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SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS STUDY

Volume III

COST AND BENEFITS
APRIL 22, 1983

CONTRACT NASW 3683

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FOREWORD

The Space Station Needs, Attributes, and Architectural Options Study contract (NASW 3683) was conducted by the Rockwell Shuttle Integration and Satellite Systems Division for NASA.

The final report summarizes the results of this study in five volumes, which are:

- Final Executive Summary Report
- Missions and Requirements
- Program Options, Architecture, and Technology
- Cost and Benefits
- DOD Task

Any questions regarding this final report should be directed to G.M. Hanley, the study manager, at (213) 922-0215.

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ILLUSTRATIONS

TABLES

1.0 COST AND PROGRAMMATIC ANALYSIS

The objective of this task is to provide the necessary cost, schedule, and cost/incremental data for analyzing various Space Operations System (SOS) capabilities and services, SOS program options, Space Station architectural options, and the plans for the evolution of a Space Station.

This task serves as a focal point within the study to evaluate the cost-effectiveness of the candidate SOS program options. System and subsystem cost and programmatic trades were performed to aid in SOS program selection and architectural approach. Analyses were conducted to quantify the potential gains to be realized as a function of proposed SOS capabilities. The end product of this task provides the cost and programmatic data to support a recommended SOS plan.

The effort is divided into four major subtasks. Parametric Cost and Schedule Analysis, Subtask 3.1, provides cost data, including life-cycle cost, annual expenditures, and user-service cost estimates. In Subtask 3.2, Cost/Incremental Capability Analysis, cost data are developed for the various capability increment options defined in Task 2. Subtask 3.3, Schedule Impact Analysis, examines selected concepts in greater detail to determine the impact of schedule variations on the annual expenditure rate. Subtask 3.4 investigates the cost-effectiveness implications of the relationship between proposed SOS capability increments.

COST AND SCHEDULE ANALYSIS

The cost analysis ground rules, guidelines, and assumptions utilized in this analysis are shown below.

- ROM level cost estimates
- 1984 dollars
- 1991 to 2000 time frame of operations
- SSCAG STD WBS used as guide only
- NASA data submittal forms (A, C, D, E, and H) used as a guide only (DRD MF003M)
- Preliminary cost risk/uncertainty analysis conducted
- Single prime contractor assumed

Rough order-of-magnitude (ROM)-type costing characterizes this effort although considerable detailed analyses of Space Station subsystem costs were conducted to provide a reasonable level of credibility in Space Station hardware development and production estimates. The work breakdown structure (WBS) developed to treat the space operations system and related-options life-cycle cost (LCC) is shown in Figure 1-1.

This WBS, in general, is compatible with that outlined by the Space Systems Cost Advisory Group (SSCAG) standard WBS and the NASA JSC manned spacecraft LCC model WBS and was amplified to include payload support elements and the transportation segment to accommodate the requirements of this study.

A simplified logic flow of the cost and programmatics analysis is shown in Figure 1-2. Detailed Space Station design characteristics (weight, design level, DDT&E, and production complexity values) were generated in Task 2 (from mission requirements developed in Task 1) to provide the basic hardware costs. The mission and systems requirements analysis (Task 1) also provided the programmatic and service requirements for developing the total SOS LCC for system selection and user cost estimates, which provided the basis for cost effectiveness analysis. A series of cost and capability increment (program options) trade-off analyses were conducted, which led to the selection of a basepoint system architecture: an evolutionary eight-man Space Station located at low inclination. The program cost description that follows elaborates on the development of the baseline program cost and illustrates the derivation of each of the cost elements in the SOS WBS. Total program (SOS) costs for a growth eight-man station are set forth in Table 1-1. A series of illustrations and discussions follow, which delineate the breakdown of program costs of the SOS segments and the WBS elements contained within them.

The system architecture study defined an evolutionary initial four-man Space Station (IOC 1991) consisting of a command module, energy module, two logistics modules, a payload support assembly, and two airlock modules. This evolved to an eight-man growth configuration by the addition of two habitation modules and a tunnel module in 1994. To accommodate a space-based OTV capability, the growth system also included a propellant tank module in the architecture. The provision for a program option that would consist of two four-man stations at low inclination rather than the growth eight-man station is also considered in the programmatic analysis. The estimated marginal cost impacts of these options are illustrated in Table 1-2.

This table provides a cost comparison of two potential evolutionary schemes from the initial four-man Space Station. The figures include only costs directly associated with the station: development and production of Space Station modules, contractor system level elements (initial spares, STE, IA C/O, SEI, and program management), Space Station logistics and assembly transportation flights, and Space Station operations and support (operating spares, ground support equipment, logistics, ground operations, flight operations, and miscellaneous operations).

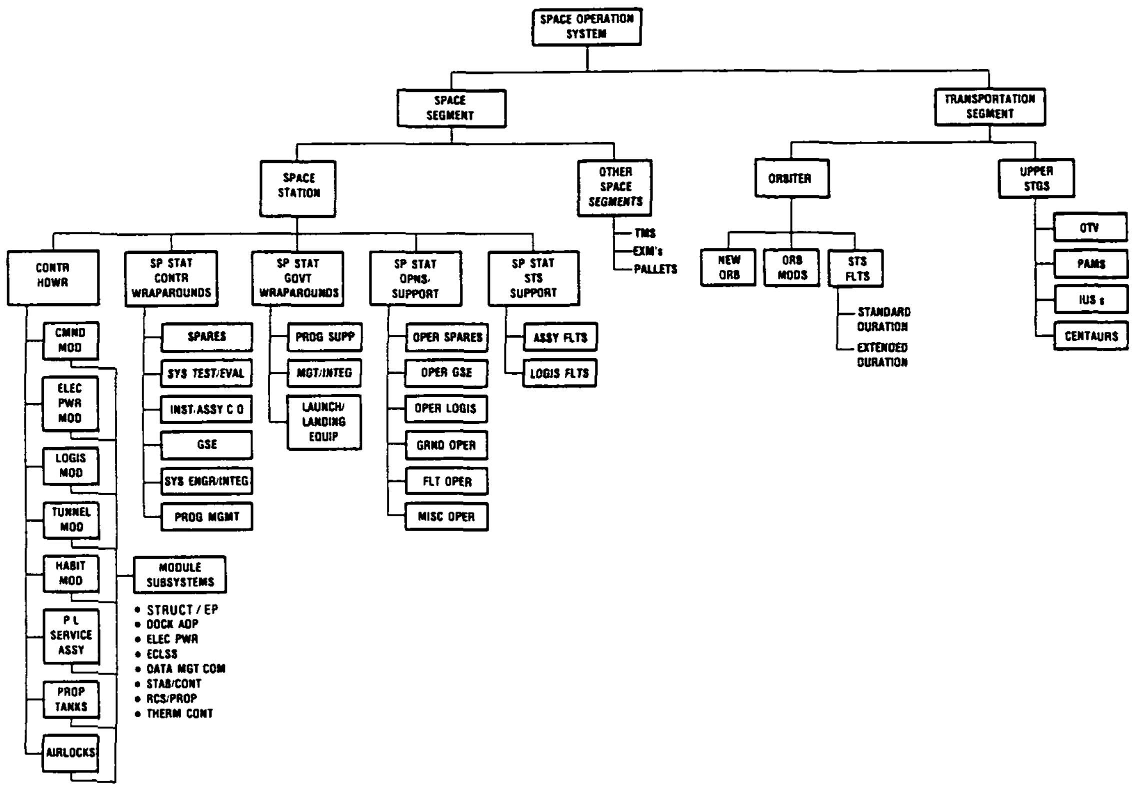


Figure 1-1. Work Breakdown Structure

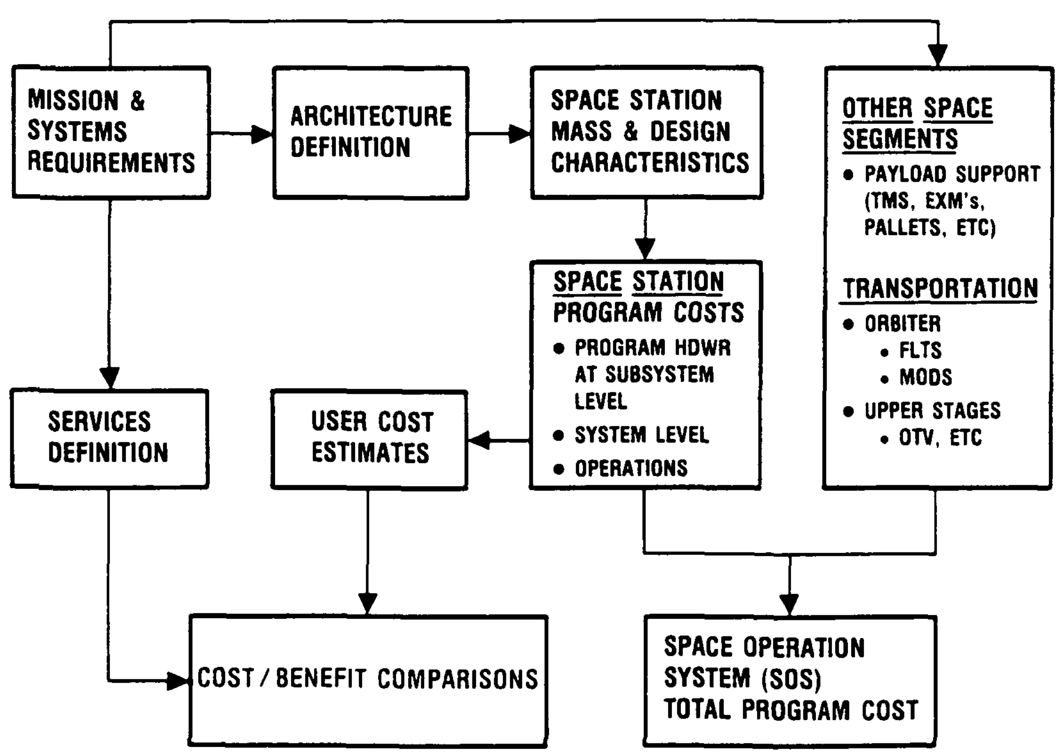


Figure 1-2. Cost and Programmatic Logic Flow

*Table 1-1. Space Operations System Life Cycle Cost--
Full-up, Eight-Man Configuration*

OPTION 3,8MAN SS UP IN '94(33K),SK,RFN,COLE-4 ,04-13-83,11 45

WBS NO	WBS NAME	DDT&E	TFU	PROD	O&S	TOTAL
1 1	ESTS PROGRAM	7871 0	888.0	2249 9	24278 6	34399 5
2 1 1	SPACE SEGMENT	6531 0	843 0	1974 9	2405 8	10911 7
3 1 1.1	SPACE STATION	6231 0	753.0	1227 9.	2405 8	9864 7
4 1 1 1 1	CONTR HARDWARE	3231 2	753 0	753 0	0 0	3984 2
5 1 1 1.1 1	CMMD MODULE	1304.5	165 6	165 6	0 0	1470 1
6 1 1 1 1 2	ELEC POWER MOD	624 0	157 6	157 6	0 0	781.6
7 1 1 1 1 3	LOGISTICS MOD-1	100 2	20 2	20 2	0 0	120 4
8 1 1 1 1 4	LOGISTICS MOD-2	0 0	20 2	20 2	0 0	20 2
9 1 1 1 1 5	TUNNEL MOD	269 8	73 9	73 9	0 0	343 7
10 1 1 1 1 6	HABIT MOD-1	430 5	109 9	109 9	0 0	540 4
11 1 1 1 1 7	HABIT MOD-2	0 0	109 2	109 2	0 0	109 2
12 1 1 1 1 8	P/L SERV ASST	253 5	32 4	32 4	0 0	285 9
13 1 1 1 1 9	PROP TANK	119 5	25 6	25 6	0 0	145 1
14 1 1 1 1 10	AIRLOCK-1	129 2	19 2	19 2	0 0	148 4
15 1 1 1 1 11	AIRLOCK-2	0 0	19.2	19 2	0 0	19 2
16 1 1 1.2	SP ST CONT WRAPS	1896 4	0 0	416 4	0 0	2312 8
17 1 1 1 2 1	SPARES	0 0	0 0	113 0	0 0	113 0
18 1 1 1 2 2	SYS TEST/EVAL	736 4	0 0	0.0	0 0	736 4
19 1 1 1 2 3	INST/ASSY&C/O	141 0	0 0	83 9	0 0	224 9
20 1 1 1 2 4	GRND SUPT EQPT	380 3	0 0	0 0	0 0	380 3
21 1 1 1 2 5	SYS ENG/INTEG	418 6	0 0	171 6	0 0	590 2
22 1 1 1 2 6	PROG MGMT	220 0	0 0	48 0	0 0	268 0
23 1 1 1 3	SP ST GOVT WRAPS	1103 5	0 0	58 5	0 0	1162 0
24 1 1 1 3 1	PROG SUPT	717 9	0 0	0.0	0 0	717 9
25 1 1 1.3 2	MGMT & INTEG	256 4	0 0	58 5	0 0	314 8
26 1 1 1 3 3	LAUNCH & LANDING	129 2	0 0	0 0	0 0	129 2
27 1 1 1.4	SP ST OPER/SUPT	0 0	0.0	0 0	1642 7	1642 7
28 1 1 1 4 1	OPER SPARES	0 0	0 0	0 0	737 0	737 0
29 1 1 1 4 2	OPER GSE	0 0	0 0	0 0	120 3	120 3
30 1 1 1 4 3	OPER LOGIS	0 0	0 0	0 0	486 4	486 4
31 1 1 1 4 4	GRND OPER	0.0	0 0	0 0	247 4	247 4
32 1 1 1 4 5	FLT OPNS	0 0	0 0	0 0	19 1	19 1
33 1 1 1 4 6	MISC OPNS	0 0	0 0	0 0	32 0	32 0
34 1 1 1 5	SP ST SYS SUPT	0 0	0 0	0.0	763 1	763 1

*Table 1-1. Space Operations System Life Cycle Cost--
Full-up, Eight-Man Configuration (Cont)*

OPTION 3,8MAN SS UP IN '94(33K),SK,RFN,COLE-4 ,04-13-83.11 45

WBS NO	WBS NAME	DDT&E	TFU	PROD	O&S	TOTAL
35 1 1 1 5 1	SUSTS ASSI	0 0	0 0	0 0	531 3	531 3
36 1 1 1 5 1	SS LOGIS	0 0	0 0	0 0	231 8	231 8
37 1 1 2	OTHER SS SGMNTS	300 0	90 0	747 0	0 0	1047 0
38 1 1 2 1	TMS	0 0	90 0	292 0	0 0	292 0
39 1 1 2 2	MMU/FHDS	0 0	0 0	25 0	0 0	25 0
40 1 1 2 3	EXP MOD 1	50 0	0 0	30 0	0 0	80 0
41 1 1 2 4	EXP MOD 2	0 0	0 0	20 0	0 0	20 0
42 1 1 2 5	EXP MOD 3	100 0	0 0	60 0	0 0	160 0
43 1 1 2 6	EXP MOD 4	150 0	0 0	320 0	0 0	470 0
44 1 1 2 7	RES PALLETS	0 0	0 0	0 0	0 0	0 0
45 1 2	TRANS SGMNT	1340 0	45 0	275 0	21872 8	23487 8
46 1 2 1	STS ORBITER	240 0	0 0	41 0	20258 7	20539 7
47 1 2 1 1	DELTA ORBITERS	0 0	0 0	0 0	0 0	0 0
48 1 2 1 2	ORBITER MODS	240 0	0 0	41 0	0 0	281 0
49 1 2 1 2 1	SLF	200 0	0 0	25 0	0 0	225 0
50 1 2 1 2 2	SP(L)	30 0	0 0	10 0	0.0	40 0
51 1.2 1 2 3	DM	10 0	0 0	6 0	0 0	16 0
52 1 2 1 3	STS FLTS - STD	0 0	0 0	0 0	20258 7	20258 7
53 1 2 1 3 1	LOW INCL	0 0	0 0	0 0	14021 7	14021 7
54 1 2 1 3 2	MED INCL	0 0	0 0	0 0	2002 0	2002 0
55 1 2 1 3 3	HIGH INCL	0 0	0.0	0 0	4235 0	4235 0
56 1 2 1 4	STS FLTS - LD	0 0	0 0	0 0	0 0	0 0
57 1 2 2	UPPER STAGES	1100 0	45 0	234 0	1614 1	2948 1
58 1 2 2 1	GB OTV	0 0	0 0	0 0	0 0	0 0
59 1 2 2 2	SB OTV	1100 0	45 0	234 0	234 0	1568 0
60 1 2.2 3	CENTAUR F	0 0	0 0	0 0	41 2	41 2
61 1 2.2 4	CENTAUR G	0 0	0 0	0 0	618 0	618 0
62 1 2 2 5	PAM A	0 0	0 0	0 0	125 4	125 4
63 1 2 2 6	PAM D	0 0	0 0	0 0	32 0	32 0
64 1 2 2 7	PAM 2	0 0	0 0	0 0	126 0	126 0
65 1 2 2 8	IUS	0 0	0 0	0 0	0 0	0 0
66 1 2 2 9	IUS 1ST STAGE	0 0	0 0	0 0	437 5	437 5
67 1.2 2.10	IUS 2 STAGE	0 0	0 0	0 0	0 0	0 0

Table 1-2. Cost Comparison of Space Station Architecture Options

	INITIAL STATION 1991-1993	4 TO 8-MAN SS 1994-2000	4 TO 2 4-MAN SS 1994-2000
DDT&E	3930	1200	170
PRODUCTION	700	470	720
O & S	800	2500	3370
TOTAL	5430	4170	4260

IN MILLIONS OF 1984 $

INCLUDES COSTS FOR SPACE STATION CONTRACTOR HARDWARE, SPACE STATION ASSEMBLY AND LOGISTICS FLIGHT COSTS, SPACE STATION OPERATIONS AND SUPPORT COSTS, AND CONTRACTOR WRAP AROUNDS

The second four-man station (in the two-station concept) is identical to the initial four-man station but with the addition of one propellant storage tank.

SPACE OPERATIONS SYSTEM LCC

Figure 1-3 displays the distribution of the total SOS LCC among five primary categories.

The Space Station category includes total costs for Space Station hardware, contractor system level costs, government system level costs, Space Station operations and support, and Space Station assembly and logistics STS flights. It includes 28 percent of the total program estimate.

The Payload Support Elements category includes total LCC (2.6 percent of the LCC) for TMS, experimental modules, and research pallets. This element is not part of the Space Station per se. The data are shown to reflect the value of this resource that was utilized in the capability option comparison discussed later.

The STS Flight and Mods category includes total costs for all STS payload flights (low, medium, and high inclination) and orbiter modifications (docking modules, storage propellant tanks, and scavenge tanks). This is the most significant resource requirement (STS flights) constituting 61 percent of the total program.

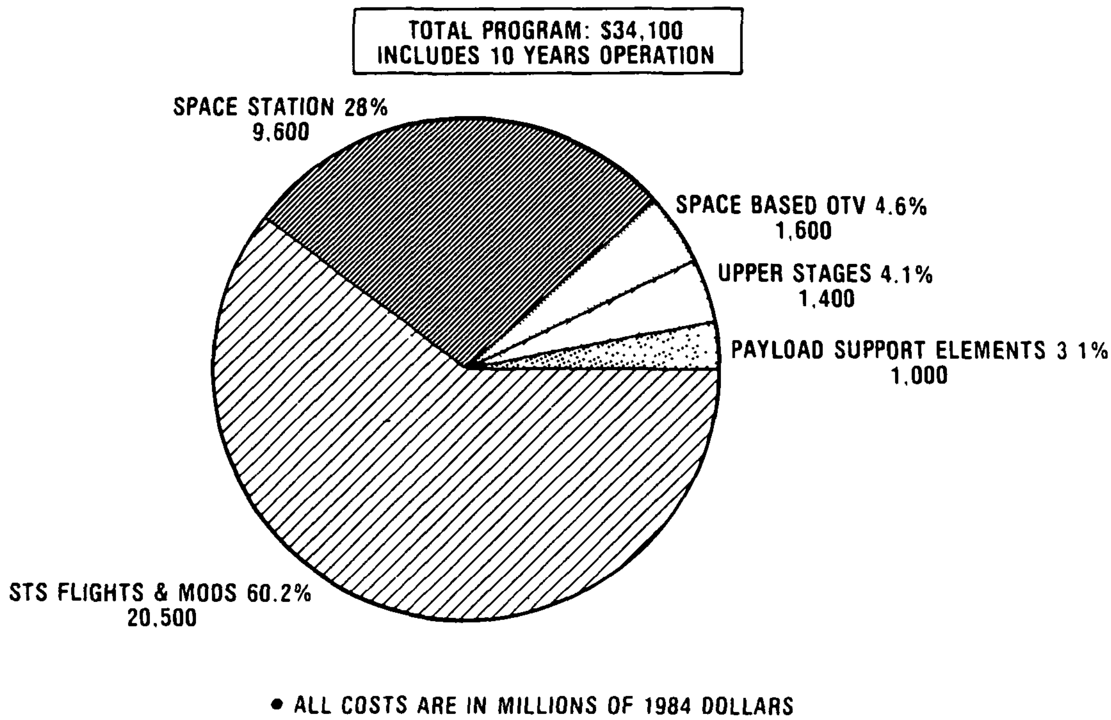


Figure 1-3. Space Operating System LCC Distribution

The Space-based OTV category includes total life cycle costs for development, and the production and refurbishment of seven space-based reusable cryo OTV's, and makes up 3.8 percent of the total LCC.

The upper stages category includes expenditures for Centaur F's, Centaur G's, PAM A's, PAM D's, PAM D2's, and IUS first stages required for high energy missions that are not accommodated by the space-based OTV. This accounts for 4.9 percent of the LCC.

SPACE STATION LIFE CYCLE COST

Figure 1-4 depicts the distribution of total Space Station (total growth configuration) LCC costs among five primary categories. The contractor hardware category includes development and production costs for the Space Station modules associated with the eight-man station. The Space Station contractor system level or wraparound costs include development and production costs for initial spares, system test and evaluation, installation, assembly and checkout, ground support equipment, system engineering and integration, and program management. The Space Station government system level category includes development and production costs for program support, management and integration, and launch and landing. This element was included in the analysis since considerable hardware resources (training simulators, launch site GSE) are involved. The Space Station operations and support category includes costs for securing operating spares, annual ground support equipment repair and

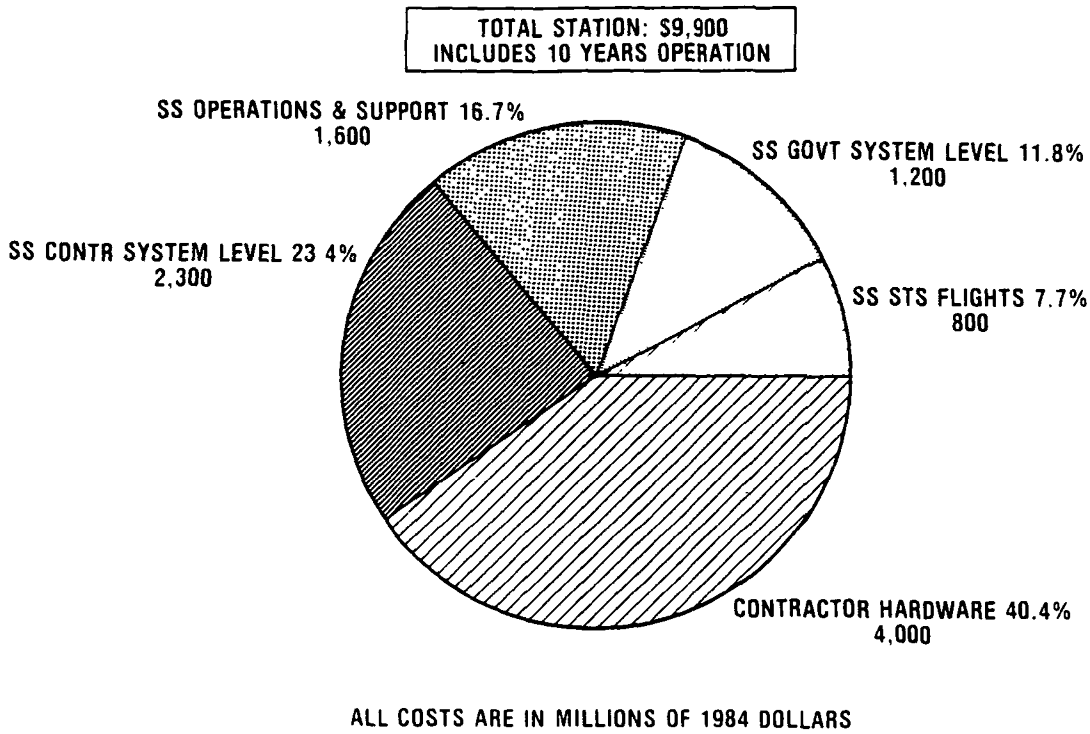


Figure 1-4. Space Station Segment LCC Distribution

maintenance, logistics, ground and flight operations, and miscellaneous operations. The Space Station STS flights category includes STS transportation costs for initial Space Station assembly and recurring logistics flights.

Figures 1-5, 1-6, and 1-7 detail the distribution of development, production, and operation costs for the Space Station, respectively.

SPACE STATION TRANSPORTATION SEGMENT

Figure 1-8 depicts how the Space Station transportation segment costs are distributed to four primary categories. The STS payload flights include costs for all STS flights (less Space Station logistics and assembly flights) based on a cost of $77 million per launch. The upper stages costs include expenditures for 1 Centaur F, 15 Centaur G's, 19 PAM A's, 5 PAM D's, 14 PAM D2's, and 35 IUS first stages from the baseline estimated requirements. The space-based OTV costs include development, production, and refurbishment of seven space-based cryo OTV's. The orbiter modification costs include development and production of scavenge tanks, docking modules, and storable propellant tanks.

Figure 1-9 shows how STS flight costs are distributed among Space Station assembly flights, Space Station logistics flights, and flights associated with transportation of other payloads. Again, costs are based on a launch cost of $77 million.

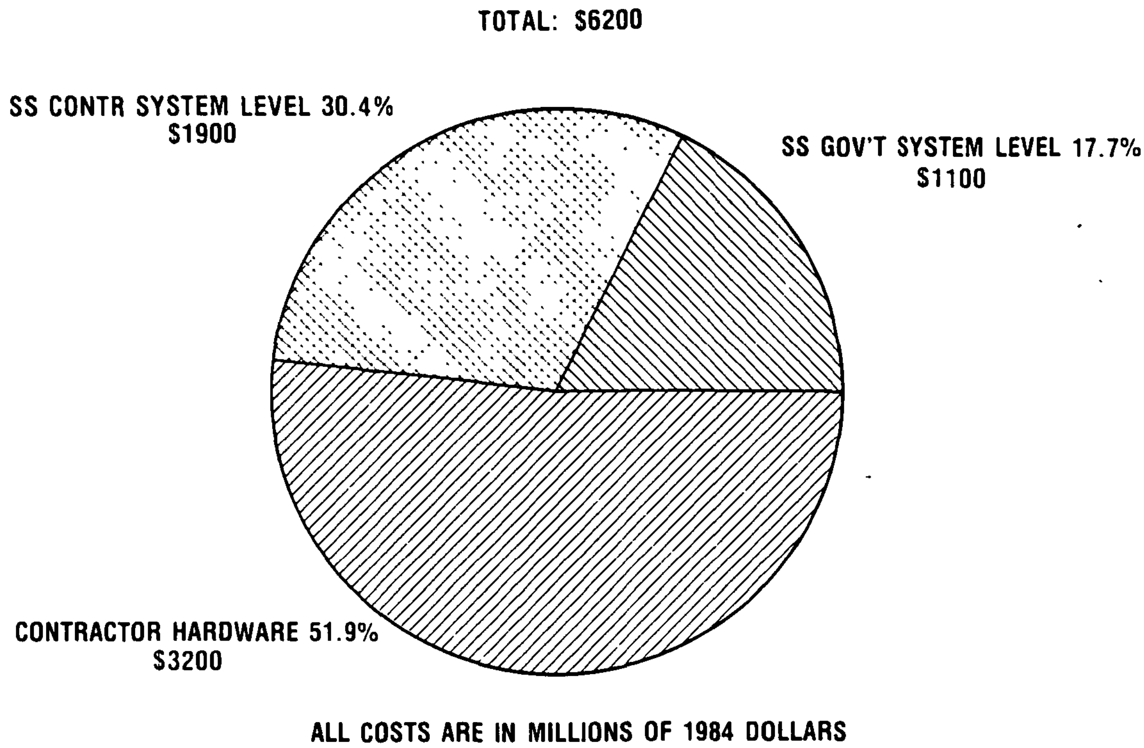


Figure 1-5. Space Station Development Costs

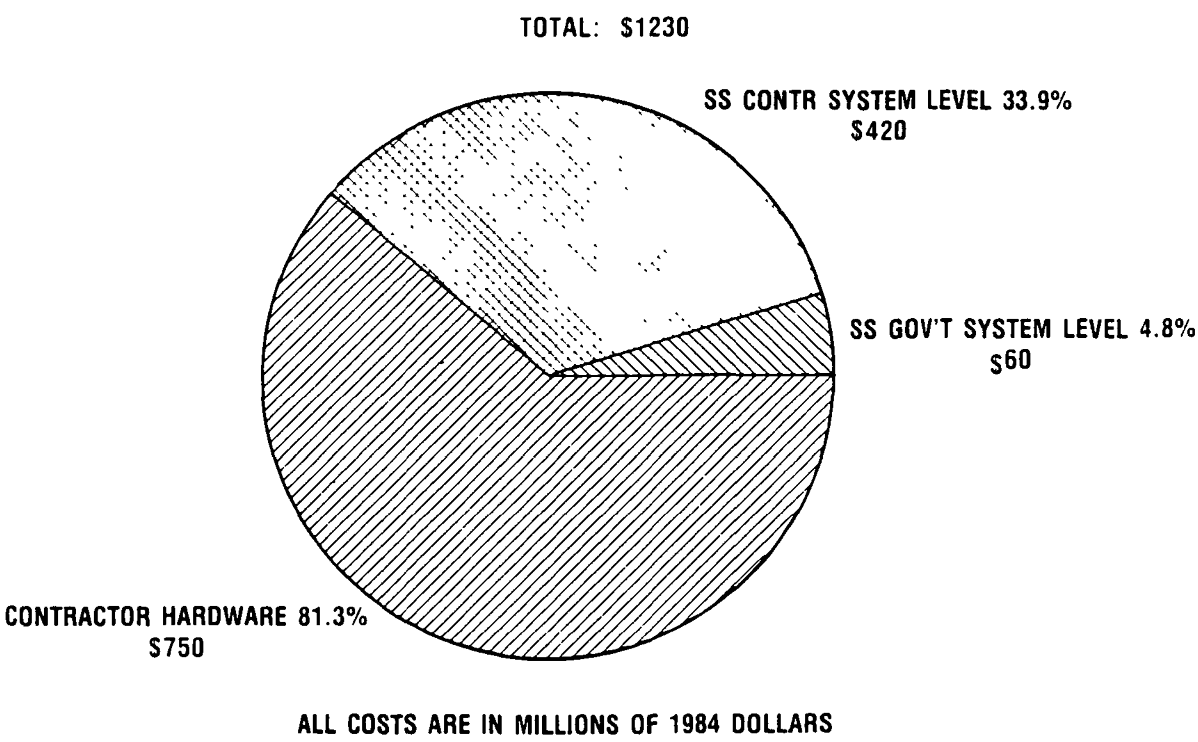
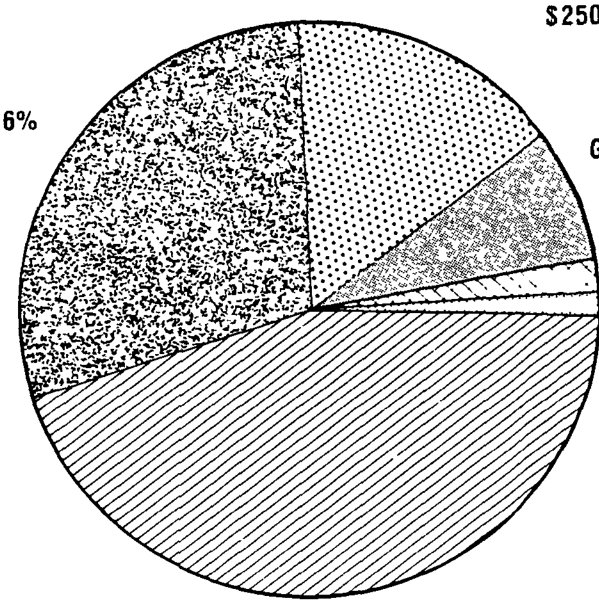


Figure 1-6. Space Station Production Costs

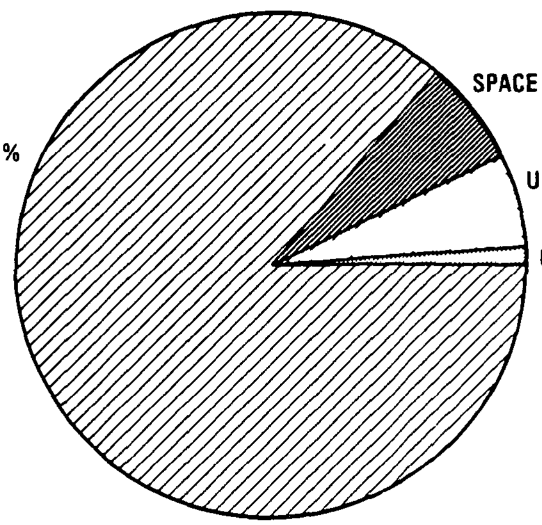
TOTAL TEN YEAR OPERATIONS: $1650



ALL COSTS ARE IN MILLIONS OF 1984 DOLLARS

Figure 1-7. Space Station Operations Costs

TOTAL FOR SEGMENT: $23,600



• ALL COSTS ARE IN MILLIONS OF 1984 DOLLARS

Figure 1-8. Space Station Transportation Segment

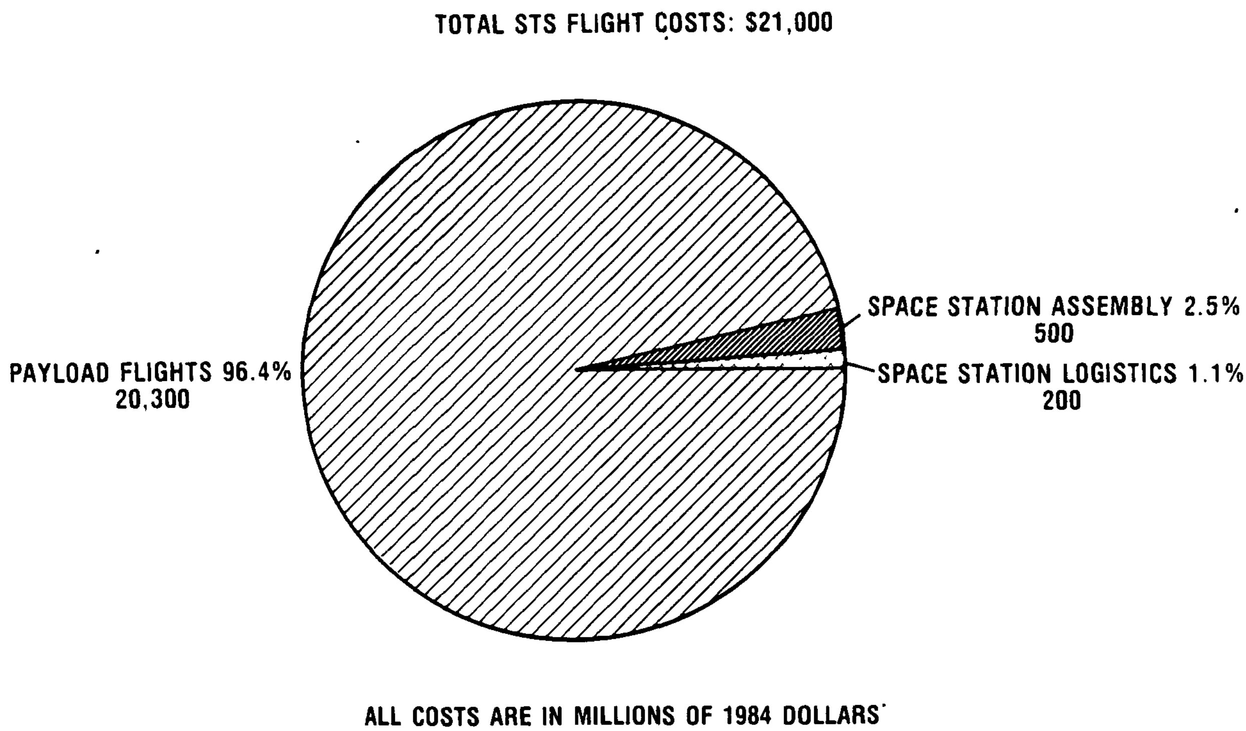


Figure 1-9. STS Flight Costs

The evolutionary eight-man Space Station model cost estimates are shown at the subsystem level in Tables 1-3 through 1-6. These are the contractor hardware costs that can be identified at the module and subsystem level and exclude system level (contractor and government wraparound) cost elements.

Figures 1-10 and 1-11 show the estimated direct and allocated cost of each of the growth and initial configuration modules. The module costs, which include the prorated contractor system level cost elements, reflect the relative time evolution of the various modules where initial or front-end DDT&E and production costs are borne most heavily by the command and electrical power modules. Subsequent modules (e.g., LM, HM, and TM) incorporate the benefit of inherited design and production and subsequently, low cost impacts are evident. Contractor hardware and contractor system level costs are compared for each of the 11 Space Station modules. Hardware development and production costs for each module were taken directly from the output of the SOS LCC model. The contractor system level development costs were distributed to each module in the same proportion as that module's hardware development cost to the total contractor hardware development cost. The contractor system level production costs were distributed to each module in a similar manner.

Table 1-3. Growth Eight-Man Configuration--Contractor Hardware Cost Detail-- Command and Electrical Power Modules

(MILLIONS OF FY '84 DOLLARS)

		DDT&E	TFU	PROD	OPNS	TOTAL
~~5 1 1 1 1 1~~	~~CMND MODULE~~	~~1304~~ 5	165 6	~~165 6~~	~~0 0~~	~~1470 1~~
6 1 1 1 1 1 1	STRUCT/EP	98 5	15 7	15 7	0 0	114 2
7 1 1 1 1 1 2	DOCK ADP	0 0	1 1	1 1	0 0	1 1
8 1 1 1 1 1 3	ELEC POWER WT	8 4	[illegible]	[illegible]	0 0	14 5
9 1 1 1 1 1 4	ECLS/CREW-OP	0 0	0 0	0 0	0 0	0 0
10 1 1 1 1 1 5	ECLS/CREW-CL	398 1	57 0	57 0	0 0	455 1
11 1 1 1 1 1 6	DATA MGT/COMM	740 6	41 4	41 4	0 0	782 0
12 1 1 1 1 1 7	GN&C	42 5	27.0	27.0	0 0	69.5
13 1 1 1 1 1 8	RCS/PROPULSION	3 6	3 3	3 3	0 0	6 9
14 1 1 1 1 1 9	THERM CONT-A	11 8	13 3	13 3	0 0	25 1
15 1 1 1 1 1 10	THERM CTL PASS	1 0	6	6	0 0	1 7
16 1 1 1 1 2	ELEC POWER MOD	624 0	157 6	157 6	0 0	781 6
~~17 1 1 1 1 2 1~~	STRUC/EP	~~96 6~~	11 2	~~11~~ 2	0 0	107 ~~7~~
18 1 1 1 1 2 2	DOCK ADP	3 6	9	9	0 0	4 5
19 1 1 1 1 2 3	ELEC POWER WT	151 5	72 2	72 2	0 0	223 7
20 1 1 1 1 2 4	ECLS/CREW-OP	0 0	0 0	0 0	0 0	0 0
21 1 1 1 1 2 5	ECLS/CREW-CL	13 3	2 1	2 1	0 0	15 4
22 1 1 1 1 2 6	DATA MGMT/COMM	65 4	11 3	11 3	0 0	76 7
23 1 1 1 1 2 7	GN&C	242 5	33 9	33 9	0 0	276 4
24 1 1 1 1 2 8	RCS/PROPULSION	32 6	4 8	4 8	0 0	37 4
~~25 1 1 1 1 2 9~~	~~THERMAL~~ CTL ACT	~~14 6~~	20 7	~~20 7~~	~~0 0~~	~~35 2~~
26 1 1 1 1 2 10	THERMAL CTL PASS	3 9	5	5	0 0	4 4

Table 1-4. Growth Eight-Man Configuration--Contractor Hardware Cost Detail-- Tunnel Module and Habitable Modules 1 and 2

(MILLIONS OF FY '84 DOLLARS)

		DDTE	TFU	PROD	OPNS	TOTAL
49 1 1 1 1 5	TUNNEL MOD	269 8	73 9	73 9	0 0	343 7
50 1 1 1 1 5 1	STRUCT/EP	34 0	15 2	15 2	0 0	49 2
~~51 1 1 1 1 5 2~~	~~DOCK ADP~~	~~0 0~~	~~1 1~~	1 ~~1~~	~~0 0~~	~~1 1~~
52 1 1 1 1 5 3	ELEC POWER WT	2 0	5	5	0 0	2 4
53 1 1 1 1 5 4	ECLS/CREW ACC-OP	0 0	0 0	0 0	0 0	0 0
54 1 1 1 1 5 5	ECLS/CREW ACC-CL	10 1	2 6	2 6	0 0	[illegible] 7
55 1 1 1 1 5 6	DATA MGMT/COMM	92 7	19 7	19 7	0 0	112 4
56 1 1 1 1 5 7	GN&C	98 8	14 4	14 4	0 0	113 2
57 1 1 1 1 5 8	RCS/PROPULSION	15 9	3 0	3 0	0 0	19 0
58 1 1 1 1 5 9	THERM CTL ACT	5 3	16 7	16 7	0 0	22 0
~~59 1 1 1 1 5 10~~	THERM CTL PASS	1 ~~0~~	~~6~~	~~6~~	~~0 0~~	~~1 7~~
60 1 1 1 1 6	HABIT MOD-1	430 5	109 9	109 9	0 0	540 4
61 1 1 1 1 6 1	STRUCT/EP	14 3	13 3	13 3	0 0	27 6
62 1 1 1 1 6 2	DOCK ADP	0 0	6	6	0 0	6
63 1 1 1 1 6 3	ELEC POWER WT	2 2	5	5	0 0	2 7
64 1 1 1 1 6 4	ECLS/CREW ACC OP	0 0	~~0 0~~	0 ~~0~~	~~0 0~~	~~0 0~~
65 1 1 1 1 6 5	ECLS/CREW ACC-CL	332 9	65 1	65	0 0	398 0
66 1 1 1 1 6 6	DATA MGMT COMM	75 8	14 3	13 3	0 0	90 1
67 1 1 1 1 6 7	GN&C	0 0	0 0	0 0	0 0	0 0
68 1 1 1 1 6 8	RCS/PROPULSION	2 0	2 3	2 3	0 0	4 3
69 1 1 1 1 6 9	THERMAL CTL ACT	2 4	13 2	13 2	0 0	15 5
70 1 1 1 1 6 10	THERMAL CTL-PASS	1 0	6	6	0 0	1 7
71 1 1 1 1 7	HABIT MOD-2	0 0	109 2	109 2	0 0	109 2
72 1 1 1 1 7 1	STRUCT/EP	0 0	13 3	13 3	0 0	13 3
73 1 1 1 1 7 2	DOCK ADP	0 0	6	6	0 0	6
74 1 1 1 1 7 3	ELEC POWER WT	0 0	5	5	0 0	5
75 1 1 1 1 7 4	ECLS/CREW ACC OP	0 0	0 0	0 0	0 0	0 0
76 1 1 1 1 7 5	ECLS/CREW ACC CL	0 0	62 8	62 8	0 0	62 8
77 1 1 1 1 7 6	DATA MGMT/COMM	0 0	18 9	18 9	0 0	18 9
78 1 1 1 1 7 7	GN&C	0 0	0 0	0 0	0 0	0 0
79 1 1 1 1 7 8	RCS/PROPULSION	0 0	0 0	0 0	0 0	0 0
80 1 1 1 1 7 9	THERMAL CTL-ACT	0 0	12 5	12 5	0 0	12 5
81 1 1 1 1 7 10	THERMAL CTL-PASS	0 0	~~6~~	6	0 0	6

Table 1-5. Growth Eight-Man Configuration--Contractor Cost Detail--Logistics Modules 1 and 2 and Payload Service Assembly

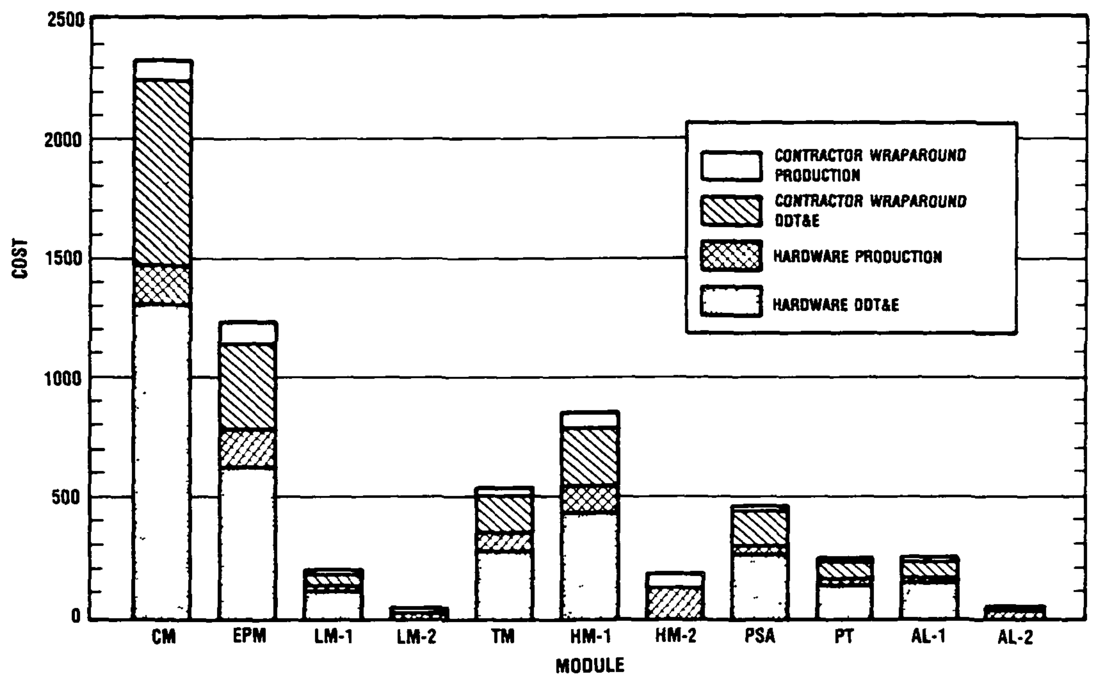
(MILLIONS OF FY '84 DOLLARS)

		DDT&E	TFU	PROD	OPNS	TOTAL
27 1 1 1 1 3	LOGISTICS MOD-1	100 2	20 2	20 2	0 0	120 4
28 1 1 1 1 3 1	STRUCT/EP	28 6	9 2	9 2	0 0	37 8
29 1 1 1 1 3 2	DOCK ADP	0 0	4	4	0 0	4
~~30 1 1 1 1 3 3~~	~~ELEC POWER WT~~	1 7	4	4	0 0	2 1
31 1 1 1 1 3 4	ECLS/CREW-OP	0 0	0 0	0 0	0 0	0 0
32 1 1 1 1 3 5	ECLS/CREW-CL	17 7	2 0	2 0	0 0	19 6
33 1 1 1 1 3 6	DATA MGMT/COMM	51 4	7 7	7 7	0 0	59 2
34 1 1 1 1 3 7	GN&C	0 0	0 0	0 0	0 0	0 0
35 1 1 1 1 3 8	RCS/PROPULSION	0 0	0 0	0 0	0 0	0 0
36 1 1 1 1 3 9	THERMAL CTL ACT	0 0	0 0	0 0	0 0	0 0
37 1 1 1 1 3 10	THERMAL CTL PASS	8	5	5	0 0	1 3
38 1 1 1 1 4	LOGISTICS MOD-2	0 0	20 2	20 2	0 0	20 2
~~39 1 1 1 1 4 1~~	~~STRUCT/EP~~	~~0 0~~	9 2	9 2	~~0 0~~	9 2
40 1 1 1 1 4 2	DOCK ADP	0 0	4	4	0 0	4
41 1 1 1 1 4 3	ELEC POWER WT	0 0	4	4	0 0	4
42 1 1 1 1 4 4	ECLS/CREW-OP	0 0	0 0	0 0	0 0	0 0
43 1 1 1 1 4 5	ECLS/CREW-CL	0 0	2 0	2 0	0 0	2 0
44 1 1 1 1 4 6	DATA MGMT/COMM	0 0	7 7	7 7	0 0	7 7
45 1 1 1 1 4 7	GN&C	0 0	0 0	0 0	0 0	0 0
46 1 1 1 1 4 8	RCS/PROPULSION	0 0	0 0	0 0	0 0	0 0
~~47 1 1 1 1 4 9~~	~~THERMAL CTL ACT~~	~~0 0~~	~~0 0~~	~~0 0~~	~~0 0~~	~~0 0~~
48 1 1 1 1 4 10	THERMAL CTL PASS	0 0	5	5	0 0	5
82 1 1 1 1 8	P/L SERV ASSY	253 5	32 4	32 4	0 0	285 9
~~83 1 1 1 1 8 1~~	~~STRUCT/EP~~	~~40 7~~	~~14 3~~	~~14 3~~	~~0 0~~	~~63 1~~
84 1 1 1 1 8 2	DOCK ADP	0 0	6	6	0 0	6
85 1 1 1 1 8 3	ELEC POWER WT	2 5	6	6	0 0	3 1
86 1 1 1 1 8 4	ECLS/CREW ACC-OP	0 0	0 0	0 0	0 0	0 0
87 1 1 1 1 8 5	ECLS/CREW ACC-CL	0 0	0 0	0 0	0 0	0 0
88 1 1 1 1 8 6	DATA MGMT/COMM	173 2	12 4	12 4	0 0	185 6
89 1 1 1 1 8 7	GN&C	0 0	0 0	0 0	0 0	0 0
90 1 1 1 1 8 8	RCS/PROPULSION	29 1	4 1	4 1	0 0	33 2
~~91~~ 1 1 1 1 8 9	~~THERMAL~~ CTL ACT	0 0	0 0	0 0	0 0	0 0
92 1 1 1 1 8 10	THERMAL CTL PASS	0 0	3	3	0 0	3

Table 1-6. Growth Eight-Man Configuration--Contractor Hardware Cost Detail--Propellant Tank and Airlocks 1 and 2

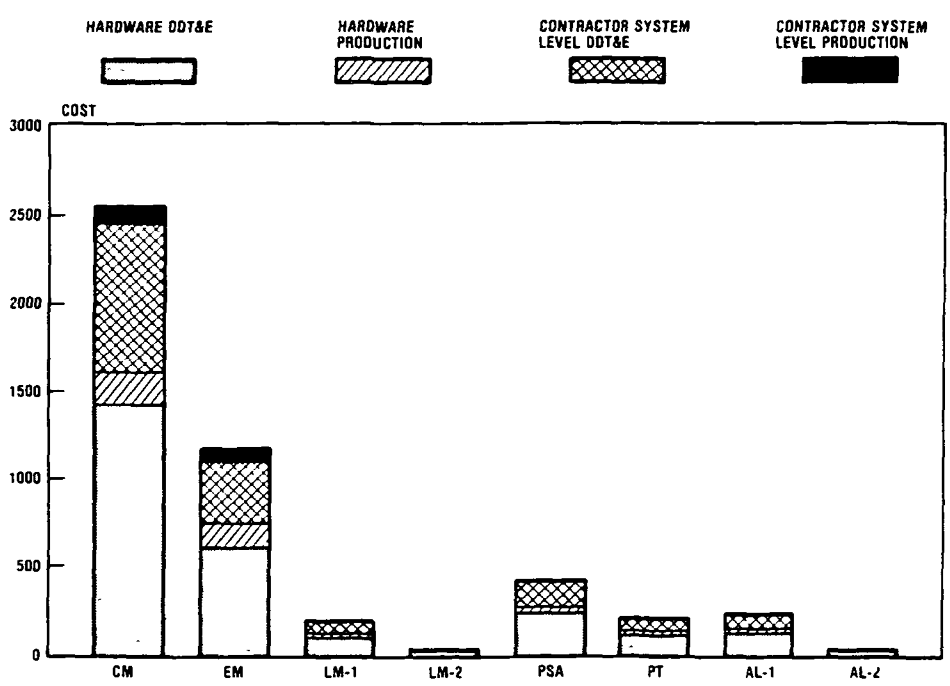
(MILLIONS OF FY '84 DOLLARS)

		DDT&E	TFU	PROD	OPNS	TOTAL
~~93 1 1 1 1 9~~	~~PROP TANK~~	~~119 5~~	~~25 6~~	~~25 6~~	~~0 0~~	~~145 1~~
94 1 1 1 1 9 1	STRUCT/EP	44 2	11 3	11 3	0 0	55 5
95 1 1 1 1 9 2	DOCK ADP	0 0	4	4	0 0	4
~~96 1 1 1 1 9 3~~	~~ELECT POWER~~ WT	1 4	3	3	0 0	1 7
97 1 1 1 1 9 4	ECLS/CREW ACC OP	0 0	0 0	0 0	0 0	0 0
98 1 1 1 1 9 5	ECLS/CREW ACC CL	0 0	0 0	0 0	0 0	0 0
99 1 1 1 1 9 6	DATA MGMT/COMM	55 6	8 8	8 8	0 0	64 4
~~100 1 1 1 1 9 7~~	~~GN&C~~	~~0 0~~	~~0 0~~	~~0 0~~	~~0 0~~	~~0 0~~
101 1 1 1 1 9 8	RCS/PROPULSION	17 4	4 3	4 3	0 0	21 7
102 1 1 1 1 9 9	THERMAL CTL ACT	0 0	0 0	0 0	-0 0	0 0
103 1 1 1 1 9 10	THERMAL CTL PASS	8	5	5	0 0	1 3
104 1 1 1 1 10	AIRLOCK-1	129 2	19 2	19 2	0 0	148 5
~~105 1 1 1 1 10 1~~	~~STRUC/EP~~	~~53 5~~	~~9 0~~	~~9 0~~	~~0 0~~	~~62 5~~
106 1 1 1 1 10 2	DOC ADP	0 0	4	4	0 0	4
107 1 1 1 1 10 3	ELECT POWER WT	4	0	0	0 0	4
108 1 1 1 1 10 4	ECLS/CREW ACC-OP	0 0	0 0	0 0	0 0	0 0
~~109 1 1 1 1 10 5~~	~~ECLS/CREW~~ ACC CL	32 4	3 8	3 8	0 0	36 2
110 1 1 1 1 10 6	DATA MGMT/COMM	42 6	5 8	5 8	0 0	48 4
111 1 1 1 1 10 7	GN&C	0 0	0 0	0 0	0 0	0 0
112 1 1 1 1 10 8	RCS/PROPULSION	0 0	0 0	0 0	0 0	0 0
~~113 1 1 1 1 10 9~~	~~THERMAL CTL ACT~~	~~0 0~~	~~0 0~~	~~0 0~~	~~0 0~~	~~0 0~~
114 1 1 1 1 10 10	THERMAL CTL PASS	4	2	2	0 0	6
~~115 1 1 1 1 11~~	~~AIRLOCK-2~~	~~0 0~~	19 2	19 2	0 0	19 2
116 1 1 1 1 11 1	STRUC/EP	0 0	9 0	9 0	0 0	9 0
117 1 1 1 1 11 2	DOC ADP	0 0	4	4	0 0	4
~~118 1 1 1 1 11 3~~	~~ELECT POWER WT~~	~~0 0~~	~~0~~	~~0~~	~~0 0~~	~~0~~
119 1 1 1 1 11 4	ECLS/CREW ACC-OP	0 0	0 0	0 0	0 0	0 0
120 1 1 1 1 11 5	ECLS/CREW ACC CL	0 0	3 8	3 8	0 0	3 8
121 1 1 1 1 11 6	DATA MGMT/COMM	0 0	5 8	5 8	0 0	5 8
~~122 1 1 1 1 11 7~~	~~GN&C~~	0 0	0 0	0 0	0 0	0 0
123 1 1 1 1 11 8	RCS/PROPULSION	0 0	0 0	0 0	0 0	0 0
124 1 1 1 1 11 9	THERMAL CTL ACT	0 0	0 0	0 0	0 0	0 0
125 1 1 1 1 11 10	THERMAL CTL PASS	0 0	2	2	0 0	2



ALL COSTS ARE IN MILLIONS OF 1984 DOLLARS

Figure 1-10. Space Station Module Costs--Growth Station



ALL COSTS ARE IN MILLIONS OF 1984 DOLLARS

Figure 1-11. Space Station Module Costs--Four-Man Initial Station

PROGRAM COST DERIVATION

The derivation of program costs is developed in this section. The basic methodology for developing the module costs was conducted at the subsystem level. A series of exponential cost estimating relationships (CER's), for the various subsystems within a module were applied as shown in Figure 1-12. An example for the structures cost of the command module is also shown in this figure. The CER's utilized for all of the subsystems are shown in Table 1-7. In order to accommodate the large number of system architecture trades in the study, the set of CER's provided through the SSCAG were utilized. The CER's reflect the proper industry-level sizing relationships for manned spacecraft systems and, therefore, were of considerable value in the analysis. Independent CER research was conducted to assess the relative validity and appropriateness of these hardware CER's and, in general, it was found that the CER's provide a reasonable level of costs. As a result, it provided validity to the system cost trade-off activity.

Design inputs to the CER's are shown for both the growth (eight-man) and initial (four-man) design in Tables 1-8 and 1-9, respectively. These data, which conform to the data reporting requirements of DRD MF 003M, were utilized in the module hardware cost estimates discussed earlier.

System level (or wraparound) cost estimates developed in the study are a significant cost item in the analysis. The general CER estimates functional form of these elements is shown in Table 1-10. Each of these element costs is a direct function of the module hardware estimates derived earlier and, in sum, constitute on the order of 60 percent of the contractor hardware estimates. Government system level costs are also indicated in the exhibit. These government system level costs are included in the analysis because significant hardware end items are involved, such as training simulators and launch integration equipment.

Space Station operations and support costs estimated for the program were developed following the methodology shown in Table 1-11. Recurring orbiter spares estimates are based on analogy to the orbiter program estimates. Other element estimates, which were examined for reasonableness, are based on CER's from the manned Space Station cost model of NASA JSC.

Payload support-element cost estimates utilized in the trade-off analysis are delineated in Table 1-12. These systems provide the basic hardware for servicing space processing and experiments, including the remote servicing and retrieval with the teleoperator. The costs shown are rough estimates only and are based on limited design considerations. Further study refinement is required in this area to lessen the relative uncertainty associated with these elements.

In Table 1-13, other study cost data for the transportation segment are set forth, including ROM estimates used for orbiter modifications (e.g., scavenging equipment, storable propellant tank, and the docking module), STS standard flight cost, the cost estimate for extended duration orbiter flights, OTV estimates, and finally, the launch cost estimates for a series of upper-stage systems utilized as part of the transportation system.

- COST ESTIMATING RELATIONSHIPS BASIC FORM
- $COST = A\ WGT_{SS}^{B}$

ADAPTED TO ESTS COST MODEL AS FOLLOWS

$$COST_{DDTE} = A\ WGT^{B} \left(\begin{array}{c}\text{PERCENT}\\ \text{NEW}\\ \text{DESIGN}\end{array}\right) \left(\begin{array}{c}\text{DESIGN}\\ \text{COMPLEXITY}\end{array}\right) \left(\begin{array}{c}\text{ESCALATION}\\ \text{INDEX}\end{array}\right)$$

EXAMPLE OF COMMAND MODULE STRUCTURE (CER BASE YEAR IS FY'78 $)

$$COST_{DDTE} = 1.013\ (11790)^{0.491}\ (.70)\ (.80)\ (1.74)$$
$$= \$98.5\overline{M}\ (FY84\ \$)$$

$$COST_{PROD} = A\ WGT^{B} \left(\begin{array}{c}\text{PRODUCTION}\\ \text{COMPLEX}\end{array}\right) \left(\begin{array}{c}\text{ESCALATION}\\ \text{INDEX}\end{array}\right) \left(\text{QUANTITY}\right)$$
$$= 0.243\ (11790)^{.44}\ (.6)\ (1.74)\ (1) = 15.7\overline{M}\ (FY\ 84\ \$)$$

Figure 1-12. Space Station Cost Estimating Methodology for Hardware

Table 1-7. Cost Estimating Relationships (CER's)

SUBSYSTEM	COEFFICIENT (FY'84 DOLLARS)		PARAMETER	SCALING EXPONENT	
	DDTE	PRODUCTION		DDTE	PRODUCTION
STRUCTURES & ENVIRONMENTAL PROTECTION	1.76	.42	SUBSYSTEM WEIGHT	.49	.44
DOCKING MODULE	0.45	.06		.49	.44
ELECTRICAL POWER	0.57	.04		.58	.78
ECLSS-CLOSED LOOP	11.72	.79		.41	.50
DATA MGT & COMM	7.81	.05		.58	.92
GN&C	4.57	.86		.52	.49
RCS/PROPUL	0.10	.11		.88	.55
THERMAL CONTROL — ACTIVE	1.50	.18		.26	.55
THERMAL CONTROL — PASSIVE	0.35	.05	WEIGHT	.42	.39

NOTE: REASONABLENESS OF ABOVE CERs HAS BEEN CHECKED WITH ANALYSIS OF OTHER SOURCES e.g., ORBITER, MODULAR SPACE STATION STUDY AND EXTENSIVE RCA PRICE RUNS CONDUCTED AT THE SUB-SUBSYSTEM LEVEL

Table 1-8. Design Inputs Per Cost Estimates--Growth Station

LEGEND: W - Weight
%D - % Design
DC - Design Complexity
PC - Production Complexity

		COMMAND MODULE	ENERGY MOD.	LOGISTICS MOD 1	LOGISTICS MOD 2	TUNNEL MOD.	HABIT. MOD 1	HABIT. MOD 2	P/L SERVICE ASSY	PROP TANK	AIRLOCK MOD 1	AIRLOCK MOD 2
STRUCTURES	W	11790	5470	5326	5326	10977	12166	12166	14524	2904	1043	1043
	%D	70	100	30	0	25	10	0	100	100	100	0
	DC	.8	.8	.8	.8	.8	.8	.8	.25	.5	1	1
	PC	.6	.6	.5	.5	.6	.5	.5	.5	.8	1	1
DOCKING	W	3063	1838	306	306	3063	613	613	613	306	306	306
	%D	0	20	30	0	0	0	0	0	0	0	0
	DC	1	1	.8	1	1	1	1	1	1	1	1
	PC	.6	.6	.5	.6	.6	.6	.6	.6	.6	.6	.6
ELEC PWR WT	W	3544	14149	334	334	432	513	513	647	252	23	23
	%D	50	100	100	0	100	100	0	100	100	100	0
	DC	.25	1	1	.1	.1	.1	.1	.1	.1	.1	.1
	PC	.25	1	1	.1	.1	.1	.1	.1	.1	.1	.1
ECLS CREW (CLOSED)	W	4994	314	263	263	465	6496	6049	0	0	138	138
	%D	100	70	100	0	90	75	0	0	0	90	0
	DC	1	.15	.15	0	.15	1	1	0	0	.4	.4
	PC	1	.15	.15	.15	.15	1	1	0	0	.4	.4
DATA MGT/ COMM.	W	2598	633	418	418	1157	816	1103	699	479	302	302
	%D	100	20	20	0	20	20	0	50	20	20	0
	DC	1	1	1	1	1	1	1	1	1	1	1
	PC	.6	.6	.6	.6	.6	.6	.6	.6	.6	.6	.6
GN&C	W	1700	2695	0	0	473	0	0	0	0	0	0
	%D	20	90	0	0	90	0	0	0	0	0	0
	DC	1	1	0	0	1	0	0	0	0	0	0
	PC	.8	.8	0	0	.8	0	0	0	0	0	0
RCS PROP	W	230	454	0	0	200	120	0	514	278	0	0
	%D	20	100	0	0	100	20	0	100	50	0	0
	DC	1.5	1.5	0	0	1.5	1.5	0	1.2	1	0	0
	PC	1.5	1.5	0	0	1.5	1.5	0	1.2	1	0	0
THERMAL CONT (ACTIVE)	W	2454	5445	0	0	3724	2418	2198	0	0	0	0
	%D	100	100	0	0	40	20	0	0	0	0	0
	DC	1	1	1	1	1	1	1	1	1	1	1
	PC	1	1	1	1	1	1	1	1	1	1	1
THERMAL CONT (PASSIVE)	W	585	308	348	348	585	591	591	125	322	52	52
	%D	20	100	20	0	20	20	0	0	20	20	0
	DC	1	1	1	1	1	1	1	1	1	1	1
	PC	1	1	1	1	1	1	1	1	1	1	1

Table 1-9. Design Inputs for Cost Estimates--Four-Man Station

LEGEND: W - Weight
%D - % Design
DC - Design Complexity
PC - Production Complexity

		COMMAND MOD	ELE PWR MOD	LOGISTICS MOD 1	LOGISTICS MOD 2	P/L SERVICE ASSY	PROP TANK	AIRLOCK MOD 1	AIRLOCK MOD 2
STRUCTURES EP	W	12411	5475	5326	5326	14524	2904	1043	1043
	%D	70	100	30	0	100	100	100	0
	DC	.8	.8	.8	.8	.25	.5	1	1
	PC	.6	.6	.5	.5	.5	.8	1	1
DOC ADP.	W	3063	1838	306	306	613	306	306	306
	%D	0	20	0	0	0	0	0	0
	DC	1	1	1	1	1	1	1	1
	PC	.6	.6	.6	.6	.6	.6	.6	.6
ELEC PWR WT	W	2327	9491	334	334	647	252	23	23
	%D	50	100	100	0	100	100	100	0
	DC	.25	1	.1	.1	.1	.1	.1	.1
	PC	.25	1	.1	.1	.1	.1	.1	.1
ECLS/CREW (CL)	W	8376	389	263	263	0	0	138	138
	%D	100	70	100	0	0	0	90	0
	DC	1	.15	1.5	0	0	0	.4	.4
	PC	1	.15	1.5	1.5	0	0	.4	.4
DATA MGT/ COMM	W	2771	633	418	418	699	479	302	302
	%D	100	20	20	0	50	20	20	0
	DC	1	1	1	1	1	1	1	1
	PC	.6	.6	.6	.6	.6	.6	.6	.6
GN&C	W	1700	3023	0	0	0	0	0	0
	%D	20	90	0	0	0	0	0	0
	DC	1	1	0	0	0	0	0	0
	PC	.8	.8	0	0	0	0	0	0
RCS/PROP	W	230	454	0	0	194	363	0	0
	%D	20	100	0	0	100	50	0	0
	DC	1.5	1.5	0	0	1.2	1	0	0
	PC	1.5	1.5	0	0	1.2	1	0	0
THERMAL CONT - "A"	W	2454	5445	0	0	0	0	0	0
	%D	100	100	0	0	0	0	0	0
	DC	1	1	1	1	1	1	1	1
	PC	1	1	1	1	1	1	1	1
THERMAL CONT - "P"	W	585	308	348	348	125	322	52	52
	%D	20	100	20	0	0	20	20	0
	DC	1	1	1	1	1	1	1	1
	PC	1	1	1	1	1	1	1	1

Table 1-10. Space Station System Level "Wraparound" CER's

CONTRACTOR		GOVT	
• INITIAL SPARES	= f (HARDWARE PRODUCTION)	• PROGRAM SUPPORT	= f (HDWR, SYSTEM LEVEL COSTS)
• SYSTEM TEST & ENGR (STE)	= f (1ST TFU UNIT PRODUCTION)	• MANAGEMENT & INTEGRATION	= f (HDWR, SYSTEM LEVEL COSTS)
• INSTALLATION, ASSY & C/O (IA C/O)	= f (STE, TFU, PROD)	• LAUNCH & LANDING	= f (HDWR)
• GSE	= f (HDWR, STE, IA C/O)		
• SYSTEMS ENGR & INTEGRATION (SEI)	= f (HDWR, & ABOVE COSTS)		
• PROGRAM MGT	= f (ABOVE COSTS)		

Table 1-11. Space Station Operations and Support Methodology

• OPERATING SPARES	— BASED ON ORBITER ANALOGY
• GSE	— ANNUAL PERCENT OF INITIAL GSE COST
• LOGISTICS (TRAIN, SIMULATORS, INVENT. CONTROL, TRANSPORTATION)	— f (FLIGHT HARDWARE COST, SPARES COST, DDTE)
• GROUND OPERATIONS (MAINT/REFURB, LAUNCH OPS, FLT TEST SUPP)	— f (FLIGHT HARDWARE COST, NO. ASSY LAUNCHES, NO. LOGIS MODULES LAUNCHED, STE COST)
• FLIGHT OPERATIONS (STATION O&M, SUPP EQUIP M&R)	— f (FLT CREW MAN-YEARS, FLIGHT HARDWARE COST)
• MISCELLANEOUS (SUSTAIN ENGR & OPER PROG MGMT)	— f (ABOVE OPERATIONS COST)

Table 1-12. Payload Support Elements

• TMS	— ASSUMED DDTE SUNK COST PRODUCTION TFU \$90M̄, 90% LEARNING CURVE		
• EXP MOD 1	— SHORT SPACELAB MOD	— DDTE	\$ 50M̄
		— PROD	\$ 30M̄
• EXP MOD 2	— LONG SPACELAB MOD	— PROD	\$ 20M̄
• EXP MOD 3	— SHORT SPACE STATION DERIVATIVE	— DDTE	\$100M̄
		— PROD	\$ 60M̄
• EXP MOD 4	— LONG SPACE STATION DERIVATIVE	— DDTE	\$150M̄
		— PROD	\$320M̄
• PALLETS	— ASSUMED INHERITED ASSETS		

Table 1-13. Transportation Segment Cost

• ORBITER MODS (SCAVENGING, STOR PROD TANK, DOCKING MODULE)		— ROM EST (\$281M̄ TOTAL)	
• STS FLIGHTS	— STANDARD FLIGHT	—	77M̄
	— EXTENDED DURATION FLT	— \$2M̄ PER DAY FOR DAYS BEYOND 5 STD DAY	
• REUSABLE SPACEBASED PKM OTV		— DDT&E	\$1100M̄
		— TFU	45M̄
			\$/LAUNCH
• UPPER STAGES		— PAM-D	6.35M̄
		PAM-D II	9.M̄
		PAM A	6.64M̄
		IUS 1ST STG	12.5M̄
		CENTAUR F	41.2M̄
		CENTAUR G	41.2M̄

TIME-PHASED EXPENDITURE ESTIMATES

Figure 1-13 shows the estimated time phased expenditures for the Space Station. The DDT&E curve is composed of contractor hardware development costs, contractor system level development costs, and government system level development costs. Contractor hardware costs (at the module system level) were spread with use of a 65-percent ogive function (65 percent of the money expended in 50 percent of the time). System level development costs were spread with use of a 75-percent ogive function. Development was assumed to begin five years prior to completion of the hardware introduction into the program. Development for most hardware begins in 1986, terminating in 1990. The only exceptions to this schedule are those modules associated with transition to the eight-man station in 1994. Development of these modules begins in 1989, terminating in 1993.

The production curve is composed of contractor hardware production costs, contractor system level production costs, and government system level production costs. As before, contractor hardware costs were spread with a 65-percent ogive function, while contractor and government system level costs were spread with a 75-percent ogive function. Production was assumed to begin one year after development and last four years.

Operations and support are composed of Space Station operations and support costs and Space Station STS flight costs associated with station assembly and logistics. The operations and support costs were calculated for both the initial and eight-man station. Three-tenths of the operations and support costs for the initial station were spread equally over the first three years (1991 to 1993) and seven-tenths of the operations and support costs for the eight-man station were spread equally over the final seven years (1994 to 2000).

The STS flight costs were determined by taking the station assembly and logistics flight charge factors per year (as manifested in the charge factor model), estimated at $77 million per flight.

Figure 1-14 depicts estimated expenditures versus time for the entire SOS program. Space Station associated costs were time-phased as outlined above. Payload support element costs were spread evenly. (Development costs were spread from 1987 to 1994, and production costs were spread from 1988 to 1994). Orbiter modification costs were spread using a 65 percent ogive function. Development costs were spread from 1986 to 1990, and production costs were spread from 1987 to 1990. STS flight costs were determined by taking the STS flight charge factors, estimated at $77 million per flight. Space-based reusable PKM development and production costs were spread with a 65-percent ogive function. Development was to begin in 1989 and terminate in 1993. Operations cost for the PKM (refurbishment) was spread evenly over the years of use (1993 to 2000). Upper-stage costs were determined by using an upper-stage requirements forecast for Centaur F, Centaur G, PAM A, PAM D, PAM D2, and IUS first-stage usage during the 1991 to 2000 time frame.

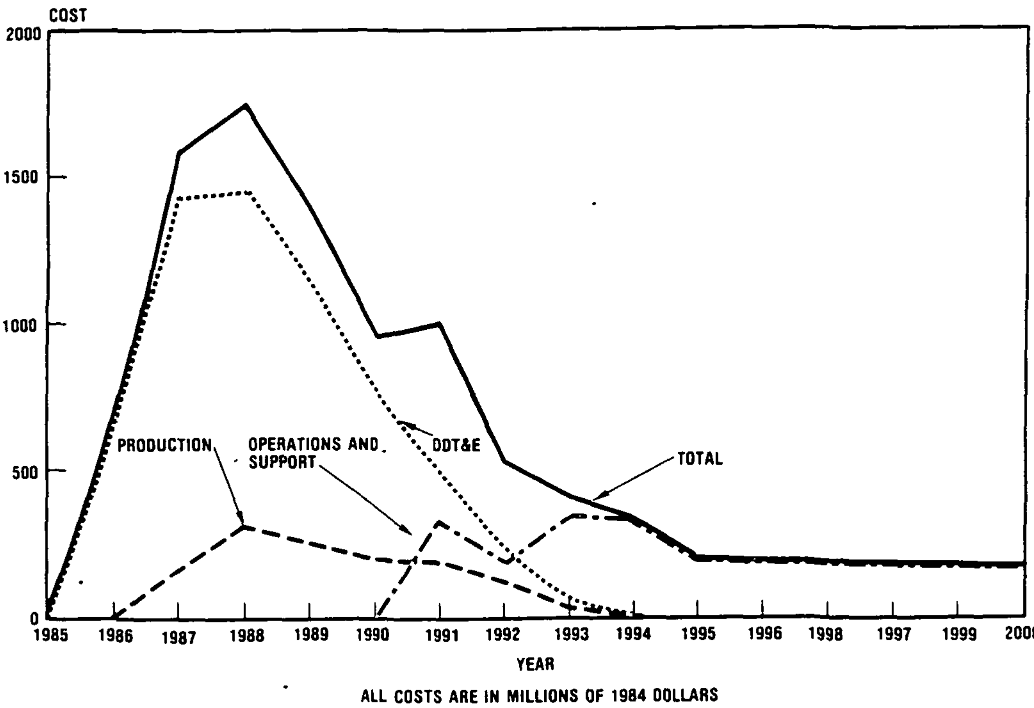


Figure 1-13. Space Station Cost Time Phasing

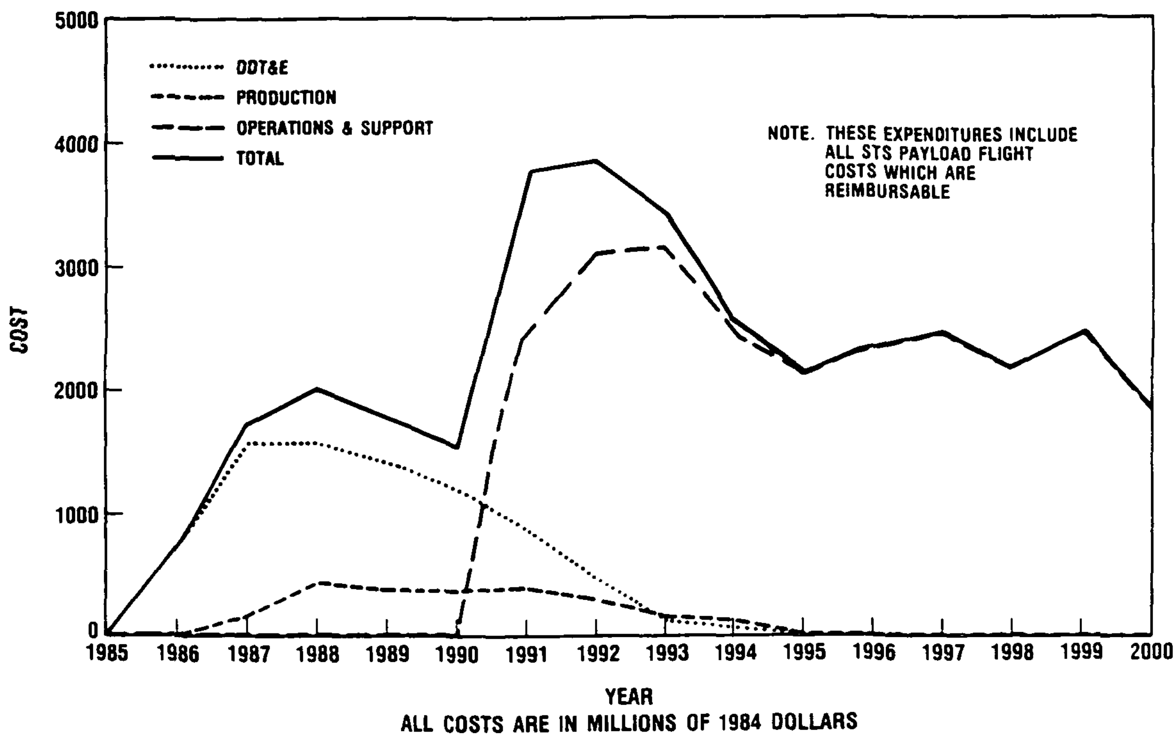


Figure 1-14. SOS Cost Time Phasing by Funding Categories

Figure 1-15 breaks the time-phased cost into three different categories (Space Station, STS payload flights, and other), but the spreading rationale remains as stated.

Table 1-14 provides data form D annual expenditure estimates for each major SOS WBS element.

COMPARISON OF OTV CANDIDATES

Figure 1-16 shows launch cost versus payload weight for five different OTV designs considered in this study. The OTV reusable PKM could use storable or cryo propellants. This gives rise to two of the designs. In these two designs it is assumed that the PKM is sized optimally for the payload weight, and that a storable AKM is used.

The third and fourth designs are off-loaded versions of the 12,000-pound capacity cryo and storable reusable PKMs. Again, storable AKMs are used. The fifth design is a single-stage, reusable cryo OTV sized optimally for payload weight.

Costs were determined by application of an OTV cost model to a detailed weight statement for each of the five designs.

Table 1-15 shows an example of the output of the OTV cost model used in Rockwell's analysis of OTV costs. The data are for a cryo, space-based, reusable PKM with a 12,000-pound payload capacity. Development and production costs were determined by applying the OTV cost model to a detailed subsystem weight statement.

Design and production complexity factors of 100 percent were used. It was later assumed that the OTV treated here would consist of 75 percent new design; this yielded a development cost of $1,100 million ($1,431 x .75). Production costs were determined assuming production of seven OTV's at a 90 percent learning rate; this yielded a total production cost of $235 million. Operating cost (refurbishment) was assumed to be 5 percent of production per pre-refurbishment mission. At a 40-mission lifetime with refurbishment after 20 missions, the total PKM operations cost is $235 million.

MODULE SUBSYSTEM COST ESTIMATES

Although detailed cost estimates were not required in this study, a decision was made to develop estimates with the use of the RCA price estimating model at the sub-subsystem level to: assist in crystallizing certain major design and cost trade-offs (e.g., an integrated ECLSS, EPS, and RCS trade) required for system architecture definition, and provide additional insight into credibility of the Space Station hardware costs. Data were preparerd for both the initial and growth configurations, seven subsystems (ECLSS, EPS, RCS, GNC, data management, communication, and thermal), and each module in the configurations studied. An example of the data management system in the logistics module of the growth configuration is illustrated in Table 1-16. The extensive data set generated in this activity is being utilized in I&RD efforts (and will be documented in Rockwells IR&D report) in several cost-related trades and the recommended architecture program cost assessment.

Table 1-14. Data Form D--Total Program Funding Schedules

NON-RECURRING (DT&E) ☒ RECURRING (PRODUCTION) ☐ RECURRING (OPERATIONS) ☐

WBS IDENTIFICATION		TOTAL COST AT COMPLETION	FISCAL YEAR							
NUMBER	NOMENCLATURE		YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8
1.1.1.1.1	COMMAND MODULE	1304.5	203.8	426.7	404.2	226.3	43.5			
1.1.1.1.2	ELEC PWR MOD	624.0	97.5	204.1	193.3	108.3	20.8			
1.1.1.1.3	LOGISTICS MOD 1	100.2	15.7	32.8	31.0	17.4	3.3			
1.1.1.1.4	LOGISTICS MOD 2	0	—	—	—	—	—			
1.1.1.1.5	TUNNEL MOD	269.8				42.1	88.3	83.6	46.8	9.0
1.1.1.1.6	HAB MOD 1	430.6				67.3	140.8	133.4	74.7	14.4
1.1.1.1.7	HAB MOD 2	0	—	—	—	—	—			
1.1.1.1.8	P/L SERVICE ASSY	253.5	39.6	82.9	78.5	44.0	8.5			
1.1.1.1.9	PROP TANK	119.5				18.7	39.1	37.0	20.7	4.0
1.1.1.1.10	AIRLOCK-1	129.2	20.2	42.3	40.0	22.4	4.3			

YR 1 = 1986

Table 1-14. *Data Form D--Total Program Funding Schedules (Cont)*

NON-RECURRING (DT&E) ☒ RECURRING (PRODUCTION) ☐ RECURRING (OPERATIONS) ☐

WBS IDENTIFICATION		TOTAL COST AT COMPLETION	FISCAL YEAR								
NUMBER	NOMENCLATURE		YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8	YR9
1.1.1.2	SP ST CONT WRAPS	1896.3	189.2	407.1	446.4	379.5	264.7	146.4	55.2	7.8	—
1.1.1.3	SP ST GOVT WRAPS	1103.4	110.1	236.9	259.8	220.8	154	85.2	32.1	4.5	—
1.1.2	OTHER SS SEGMENTS	300.0	—	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5
1.2.1.2	ORBITER MODS	240.0	37.5	78.5	74.4	41.6	8.0	—	—	—	—
1.2.2.2	SB OTV	1100.0	—	—	—	171.8	359.8	340.8	190.9	36.7	—
TOTAL • DDT&E		7871.0	713.6	1548.8	1565.1	1397.7	1172.6	863.9	457.9	113.9	37.5

Table 1-14. Data Form D--Total Program Funding Schedules (Cont)

NON-RECURRING (DT&E) ☐ RECURRING (PRODUCTION) ☒ RECURRING (OPERATIONS) ☐

WBS IDENTIFICATION		TOTAL COST AT COMPLETION	FISCAL YEAR							
NUMBER	NOMENCLATURE		YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8
1.1.1.1.1	COMMAND MODULE	165.6		38.1	69.5	47.8	10.2			
1.1.1.1.2	ELEC PWR MOD	157.6		36.3	66.2	45.5	9.7			
1.1.1.1.3	LOGIST. MOD 1	20.2		4.6	8.5	5.8	1.2			
1.1.1.1.4	LOGIST. MOD 2	20.2		4.6	8.5	5.8	1.2			
1.1.1.1.5	TUNNEL MOD	73.9					17.0	31.0	21.3	4.5
1.1.1.1.6	HAB MOD 1	109.9					25.3	46.1	31.7	6.7
1.1.1.1.7	HAB MOD 2	109.2					25.1	45.9	31.5	6.7
1.1.1.1.8	P/L SERVICE ASSY	32.4		7.5	13.6	9.4	2.0			
1.1.1.1.9	PROP TANK	25.6					5.9	10.8	7.4	1.6
1.1.1.1.10	AIRLOCK-1	19.2		4.4	8.1	5.5	1.2			
1.1.1.1.11	AIRLOCK-2	19.2		4.4	8.1	5.5	1.2			

Table 1-14. *Data Form D--Total Program Funding Schedules (Cont)*

NON-RECURRING (DT&E) ☐ RECURRING (PRODUCTION) ☒ RECURRING (OPERATIONS) ☐

WBS IDENTIFICATION		TOTAL COST AT COMPLETION	FISCAL YEAR								
NUMBER	NOMENCLATURE		YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8	YR9
1.1.1.2	SP ST CONT WRAPS	416.4	—	52.5	106.9	108.0	81.5	47.0	18.1	2.6	—
1.1.1.3	SP ST CONT WRAPS	58.5	—	7.4	15.0	15.2	11.4	6.6	2.5	.4	—
1.1.2	OTHER S.S. SEGMNTS	747.0	—	—	106.7	106.7	106.7	106.7	106.7	106.7	106.7
1.2.1.2	ORBITER MODS	40.9	—	9.4	17.2	11.8	2.5	—	—	—	—
1.2.2.2	SB OTV	234.0	—	—	—	—	53.8	98.3	67.5	14.4	—
TOTAL • PRODUCTION		2249.8	—	169.2	428.3	367.0	355.9	392.4	286.7	143.6	106.7

Table 1-14. Data Form D--Total Program Funding Schedules (Cont)

NON-RECURRING (DT&E) ☐ RECURRING (PRODUCTION) ☐ RECURRING (OPERATIONS) ☒

WBS IDENTIFICATION		TOTAL COST AT COMPLETION	86			FISCAL YEAR				93			FISCAL YEAR				2000
NUMBER	NOMENCLATURE		YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR13	YR14	YR15
1 1 1 4.1	OPERATION SP	737 0	—	—	—	—	—	66 0	66 0	66 0	77.0	77 0	77 0	77.0	77 0	77 0	77 0
1.1.1 4 2	OPERATION GSE	120 8	—	—	—	—	—	11 1	11 1	11.1	12.5	12.5	12.5	12.5	12 5	12 5	12 5
1 1 1 4.3	OPER LOGIC	486 4	—	—	—	—	—	36 1	34 2	34 2	54.9	54 5	54.5	54.5	54 5	54.5	54.5
1 1.1 4.4	GRND OPER	247 4	—	—	—	—	—	28 3	19 5	19.5	29.5	25.1	25.1	25 1	25 1	25 1	25 1
1 1 1 4.5	FLT OPNS	19 1	—	—	—	—	—	1 3	1.3	1.3	2.2	2 0	2.2	2.2	2 2	2.2	2.2
1.1.1 4 6	MISC. OPNS	32 0	—	—	—	—	—	2.5	2.5	2.5	3.5	3.5	3 5	3 5	3.5	3 5	3 5
1.1.1 5 1	SS STS ASSY	531.3	—	—	—	—	—	184.8	38 5	215.6	92.4	—	—	—	—	—	—
1 1 1.5 2	SS LOGIS	231 8	—	—	—	—	—	7.7	77.0	69.3	53.9	23.1	0.8	0.8	0.8	0 8	0.8
1 2 1 3 1	LOW INCL	14021 7	—	—	—	—	—	962.5	1501 5	1255 1	1470.7	1439.9	1617.0	1617.0	1309.0	1694.0	1155.0
1 2 1.3 2	MED INCL	2002 0	—	—	—	—	—	462.0	385.0	539.0	77.0	77.0	154.0	77 0	77.0	77.0	77 0
1 2 1 3.3	HIGH	4235.0	—	—	—	—	—	385.0	462 0	385 0	462.0	308.0	308 0	539.0	539.0	462 0	385 0
1 2.2.2	SB OTV	234 0	—	—	—	—	—	—	—	29 3	29 3	29.3	29 3	29 3	29 3	29 3	29.3

Table 1-14. Data Form D--Total Program Funding Schedules (Cont)

NON-RECURRING (DT&E) ☐ RECURRING (PRODUCTION) ☐ RECURRING (OPERATIONS) ☒

WBS IDENTIFICATION		TOTAL COST AT COMPLETION	86	FISCAL YEAR						93		FISCAL YEAR					2000
NUMBER	NOMENCLATURE		YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR13	YR14	YR15
1 2 2 3	CENTAUR-F	41.2						—	41 2	—	—	—	—	—	—	—	—
1 2 2 4	CENTAUR-G	618 0						164 8	206 0	247 2	—	—	—	—	—	—	—
1.2 2.5	PAM-A	125 4						13.2	39 6	26 4	13 2	6 6	13.2	6.6	—	6.6	—
1.2.2.6	PAM-D	32.0						6 4	12 8	12.8	—	—	—	—	—	—	—
1 2 2 7	PAM-2	126 0						18 0	36 0	36.0	18.0	9 0	9 0	—	—	—	—
1.2.2 9	IUS 1ST STAGE	437.5						137 5	137.5	162.5	—	—	—	—	—	—	—
TOTAL																	
• DDT&E	—	7871 0	713 6	1548 8	1565 1	1397 7	1172 6	863 9	457 9	113 9	37.5						
• PRODUCTION	—	2249 8	—	169 2	428 3	367 0	355 9	392 4	286 7	143 6	106 7						
• OPERATIONS	—	24278.6	—	—	—	—	—	2487.2	3071.7	3112.8	2396.1	2067.5	2305.3	2443.7	2129.1	2443.7	1821 1
GRAND TOTAL																	
• LIFE CYCLE COSTS		34399 4	713 6	1718 0	1993 4	1764 7	1528 5	3743 5	3816 3	3370 3	2540 3	2067.5	2306 6	2443 6	2129 1	2443.7	1821.1

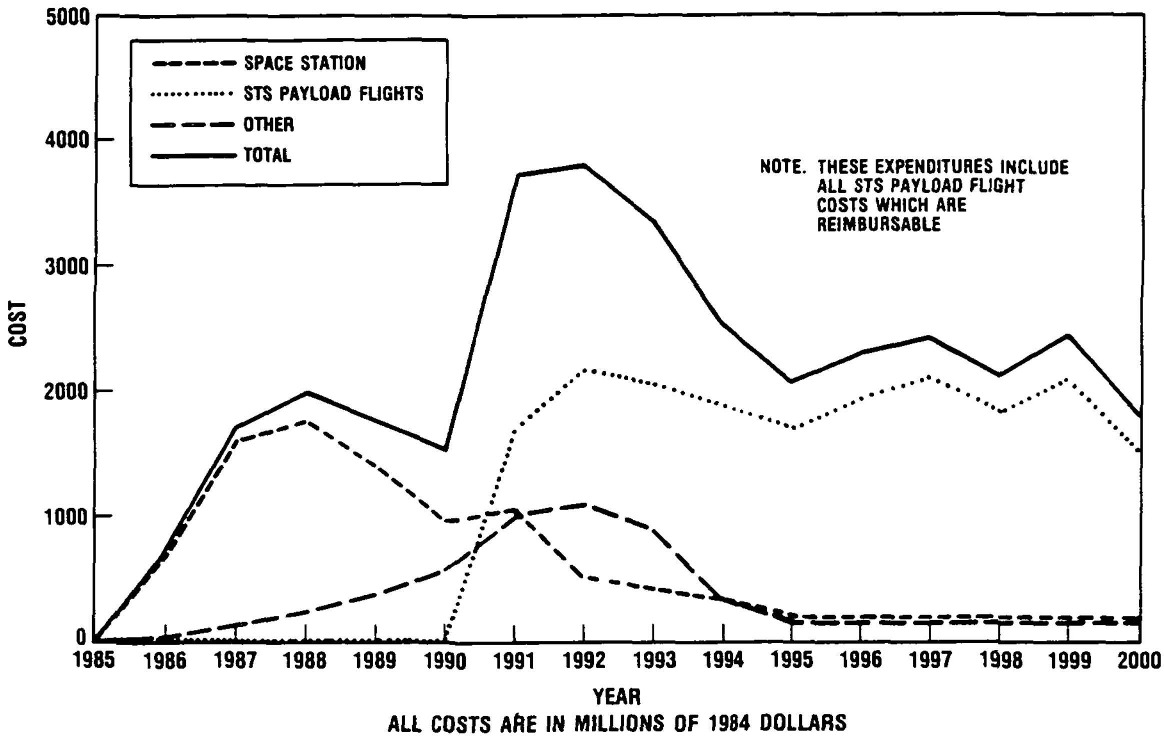


Figure 1-15. SOS Cost Time Phasing by Major Cost Categories

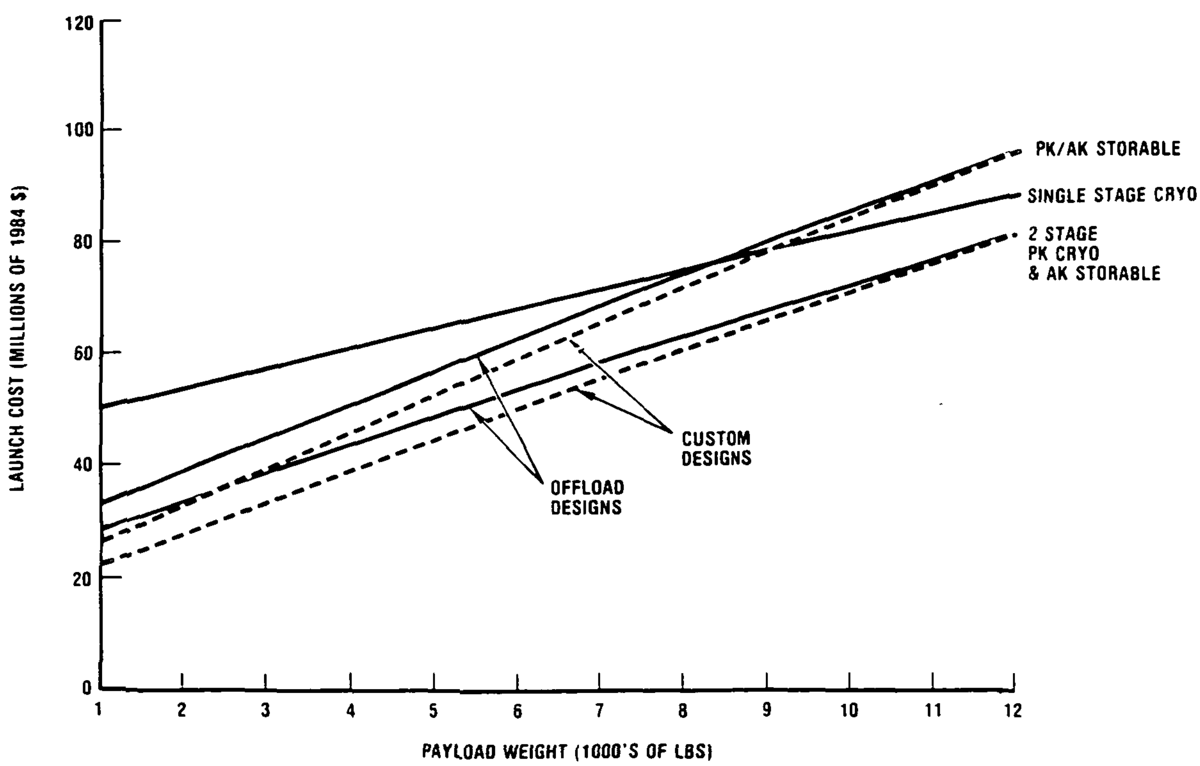


Figure 1-16. OTV Launch Cost Versus Payload Weight

Table 1-15. Reusable Space-Based Perigee Kick OTV DDT&E (100%) and First Unit Production Cost

(FY 1984 $M)

OTV COSTS: CASE CSR-12; 1-7-83; 17:38

WBS NO.	WBS NAME	DDT&E	TFU	PROD	O&S	TOTAL
1 1	OTV	1430.6	45.0	45.0	0.0	1475.5
2 1.1	AIRFRAME	1127.7	42.3	42.3	0.0	1170.0
3 1.1.1	STRUC & THERM	180.6	3.2	3.2	0.0	183.8
4 1.1.2	DROP TANK	0.0	0.0	0.0	0.0	0.0
5 1.1.3	AVIONICS	765.1	33.9	33.9	0.0	799.0
6 1.1.3.1	GUIDANCE & NAV	241.8	15.1	15.1	0.0	256.9
7 1.1.3.2	COMMUNICATIONS	288.4	13.2	13.2	0.0	301.7
8 1.1.3.3	INSTRUMENTATION	234.8	5.6	5.6	0.0	240.4
9 1.1.4	ECLSS	0.0	0.0	0.0	0.0	0.0
10 1.1.5	ELEC POWER	165.2	3.4	3.4	0.0	168.6
11 1.1.5.1	FUEL CELL	165.2	3.4	3.4	0.0	168.6
12 1.1.5.2	SOLAR/BATTERY	0.0	0.0	0.0	0.0	0.0
13 1.1.5.3	BATTERY ONLY	0.0	0.0	0.0	0.0	0.0
14 1.1.6	HYDRAULIC PWR	16.8	1.8	1.8	0.0	18.6
15 1.2	PROPULSION	232.0	1.0	1.0	0.0	233.0
16 1.2.1	ROCKET ENGINES	207.1	6	.6	0.0	207.7
17 1.2.2	ORIENTATION CONT	24.9	.4	.4	0.0	25.3
18 1.3	INITIAL TOOLING	43.2	0.0	0.0	0.0	43.2
19 1.4	GROUND SUPPORT E	27.7	0.0	0.0	0.0	27.7
20 1.5	INTEG & ASSY	0.0	1.7	1.7	0.0	1.7

Table 1-16. Example of Detailed "Price" Estimate Data Management System in the Logistics Module Full-up Eight-Man Configuration

— — — PRICE 84 — — —
ELECTRONIC ITEM

DATE 2-MAR-83 TIME 03:18 (283010) FILENAME SKDM5 DAT

PROGRAM COST ($1000)	DEVELOPMENT	PRODUCTION	TOTAL COST
MODULE COMPUTER			
TOTAL COST	2901.	3904	6804
BUS CONTROL UNIT			
TOTAL COST	1712	2360	4072.
MASTER CONTROL CONSOLE			
TOTAL COST	1833	1449	3281
MASTER TIMNG UNIT			
TOTAL COST	835	1237	2072
MICROPROCESSOR, POWER CONTROL			
TOTAL COST	401	640	1041
MICROPROCESSOR, THERMAL			
TOTAL COST	401	640	1041
MICROPROCESSOR, ANNUNCIATOR			
TOTAL COST	401	640	1041
REMOTE INTERFACE UNIT			
TOTAL COST	980.	1300	2280
C & W DISPLAY			
TOTAL COST	144	158.	302.
DATA BASE COUPLER			
TOTAL COST	13.	22	35.
DATA BASE I/F AMP			
TOTAL COST	21	27	48.
PORTABLE CONTROL PANEL			
TOTAL COST	43.	61	105
DATA BUS			
TOTAL COST	651	124	774
LM INFO MGT SUBSYT INTEG/TEST			
TOTAL COST	1945.	2938	4883.

NOTE: DATA WERE DEVELOPED TO ASSIST IN DETERMINING COST ESTIMATE CREDIBILITY AND FOR SUBSYSTEM OPTIMIZATION STUDIES

COST RISK/UNCERTAINTY ANALYSIS

Figure 1-17 illustrates a preliminary estimate of uncertainty for the total space operations system cost generated by a beta distribution-based Monte Carlo simulation program after 10,000 iterations. Optimistic, pessimistic, and assessment values were entered for Space Station contractor hardware, Space Station contractor system level, Space Station government system level, Space Station operations and support, Space Station STS support, other Space Station segments, STS orbiter, space-based reusable PKM, and upper stage total costs.

A beta distribution was fit to each cost according to its optimistic, pessimistic, and assessment estimates. A Monte Carlo simulation determined the distribution on the sum of the individual costs. For the graph shown, independency between cost distributions was assumed.

Figures 1-18, 1-19, and 1-20 depict uncertainty due to standard errors in the JSC CER for Space Station contractor hardware subsystem costs. Figure 1-18 shows the standard error uncertainty for total contractor hardware cost (DDT&E and production). To develop optimistic and pessimistic cost estimates for each module, it was necessary to assume independence between development and production costs for each subsystem. The distribution on the total was generated using the Monte Carlo simulation mentioned above.

The same program was used to generate the distribution on total DDT&E costs and total production costs. The results are shown in Figures 1-19 and 1-20.

MISSION PAYLOAD COST FORECASTS

Mission forecast costs (contractor level only) shown in Figure 1-21 were estimated to provide feedback and a check on the cost implications of the low, medium, and high mission model forecasts to determine the reasonableness of the forecast. The total payload costs comparison of low, medium, and high models for DOD, shown in Figure 1-21, were developed using cost formulas developed by the Aerospace Corporation which are sensitive to the complexity of the spacecraft (e.g., surveillance, scientific, meteorological, communications, and navigation). The time-phased costs developed therefore reflect various types of DOD payload complexity factors used in the calculation of production and development.

Once the costs are determined through the use of a computer program, spreading of annual expenditure data are obtained with the use of the ogive technique. For example, 65 percent of the funds allocated for a specific satellite were assumed spent in the first 50 percent of the production or DDT&E phase. DDT&E and production costs are spread four years prior to the year of launch. In cases where multiple identical satellites are sent up, but have gaps in the years of launch, the production spread is stretched within a logical amount of time (so as to avoid restart costs) and the second or follow-on of the series is stored for a few years if necessary. NASA and other government mission payload cost forecasts are shown in Table 1-17. These are budgetary-type estimates based on historical levels and were utilized to develop the mission payload forecasts.

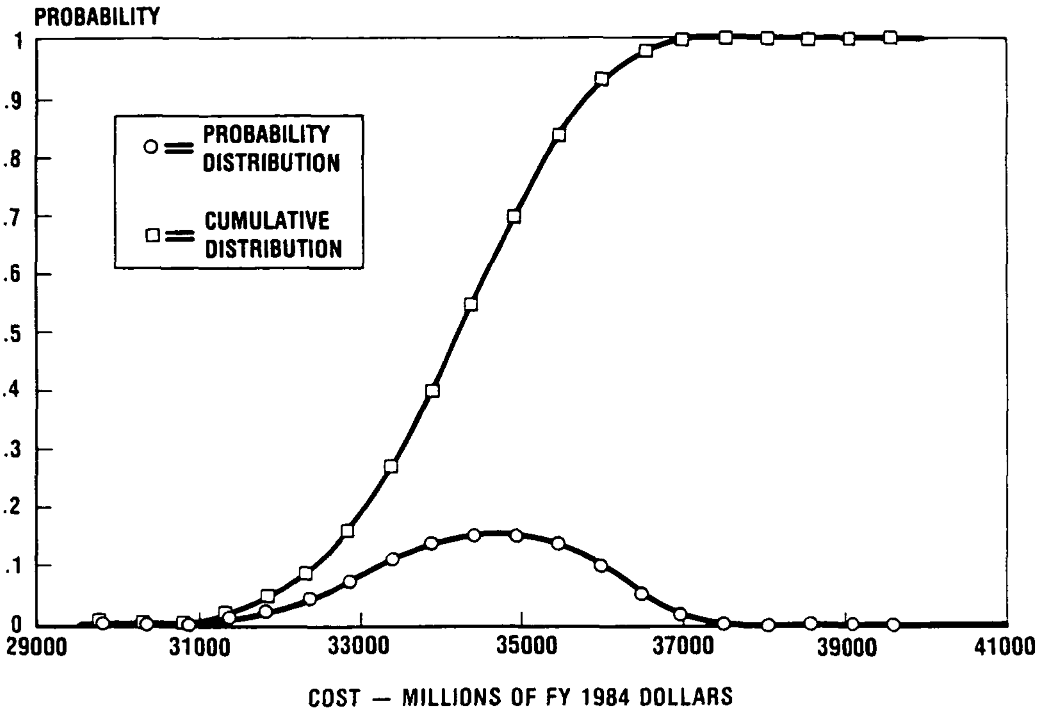


Figure 1-17. SOS Cost Uncertainty

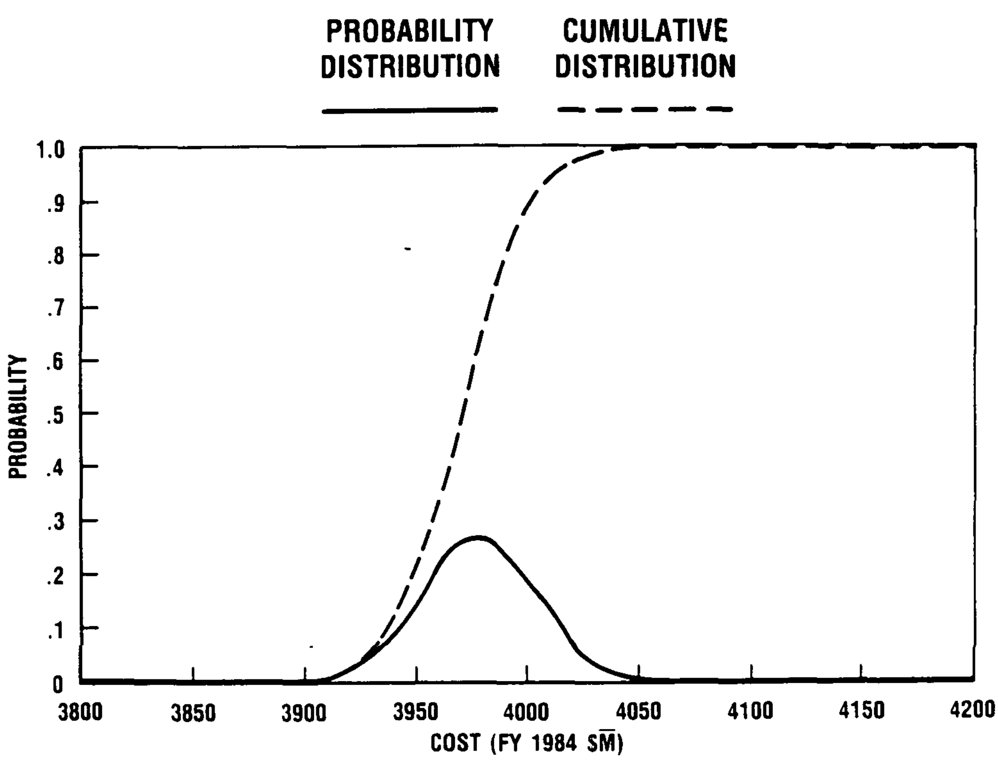


Figure 1-18. Total Standard Error Analysis--Space Station Hardware DDT&E and Production

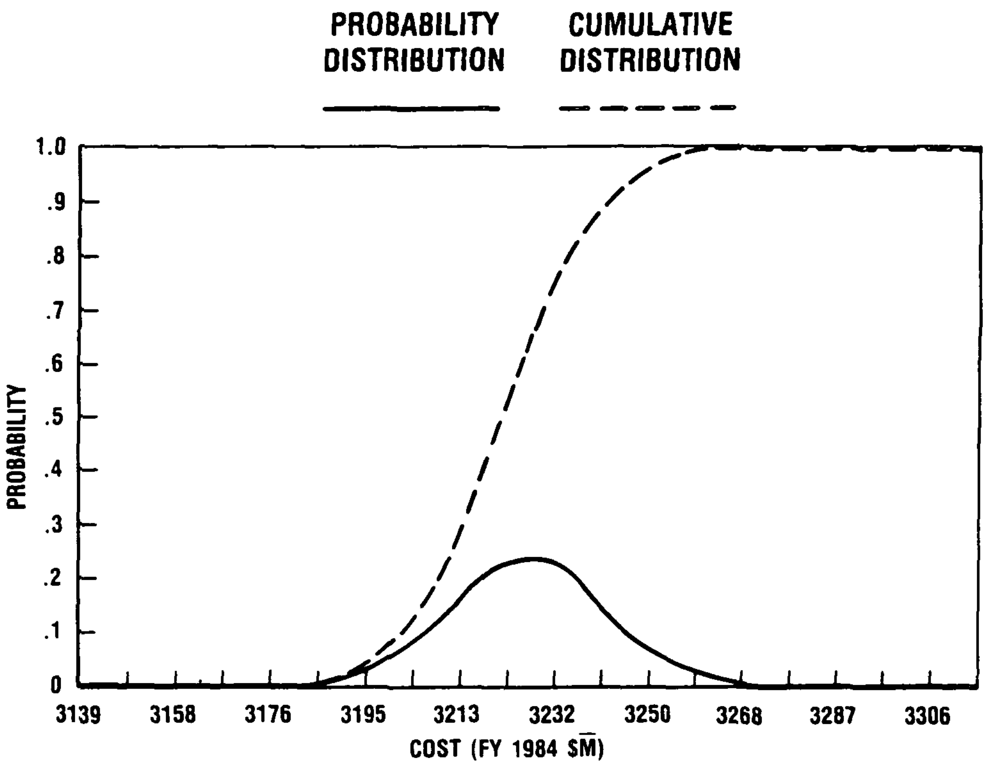


Figure 1-19. Space Station Hardware DDT&E Standard Error Analysis

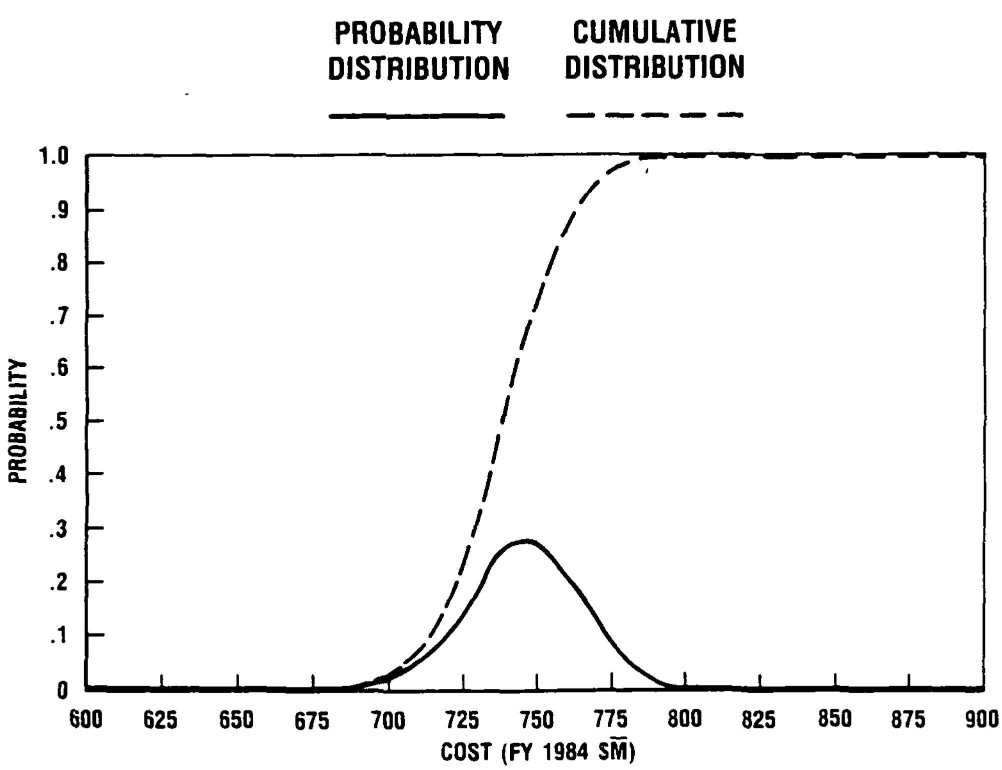


Figure 1-20. Space Station Hardware Production Standard Error Analysis

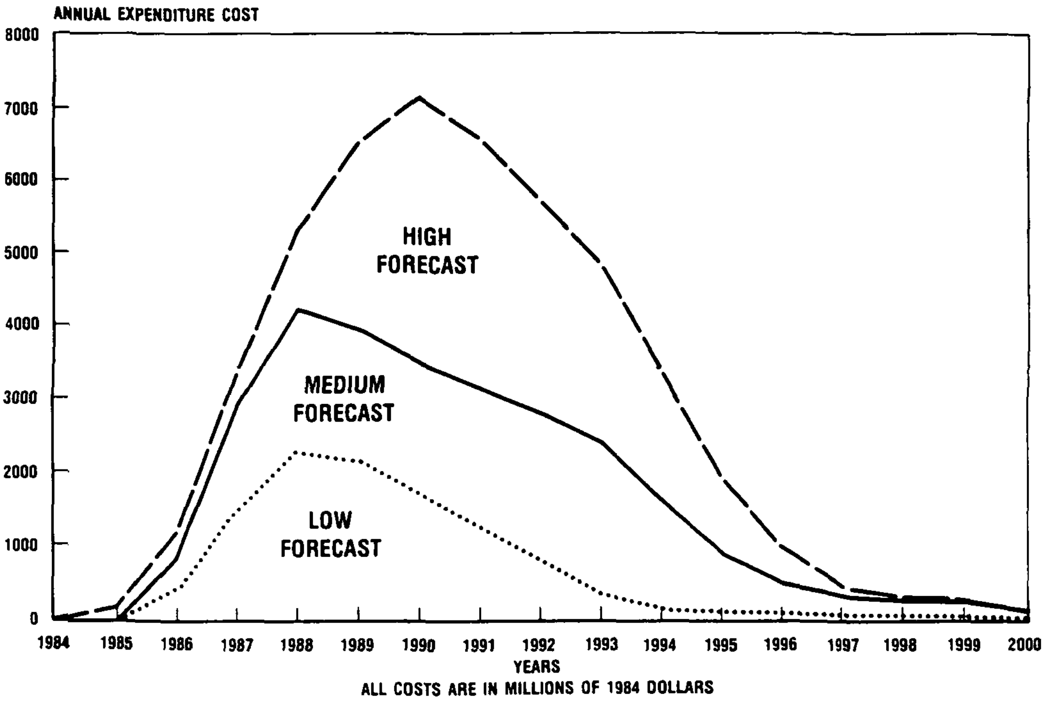


Figure 1-21. Total DOD Payload Cost Forecast--Comparison of Low, Medium, and High Models--Scenario 6

Table 1-17. Distribution of Science and Applications Payload Costs (Average Years 1991 to 2000)

ANNUAL EXPENDITURES (MILLIONS OF 1984 $)

	MODEL 6 W/SPACE STATION			MODEL 6 W/O SPACE STATION
	HIGH	MEDIUM	LOW	MEDIUM
SCIENCE FLIGHT PROGRAMS	654	654	350	425
SCIENCE RESEARCH BASE	309	309	309	309
APPLICATIONS FLIGHT PROGRAMS & RESEARCH BASE	370	370	341	370
PREDICTED S&A AVERAGE BUDGET 1991-2000	$1331	$1331	$1000	$1104

COST/INCREMENTAL CAPABILITY ANALYSIS

As part of our initial study of capability increments, a number of Space Station programmatic options were evaluated for Mission Scenario 4. This evaluation, which follows, allowed determination of the optimal Station architecture used in the further incremental capability analyses. These analyses examine option cost comparisons and user costs for Scenario 6. To enhance the incremental capability analysis, another mission scenario (6A) was formulated.

OPTION COST COMPARISON, SCENARIO 4

The definition of each of the options studied is set forth in the program options, architecture, and technology volume of this report. These are highlighted in Table 1-18. Total program life cycle costs, determined for each of these options, are illustrated in Figure 1-22. The cost data are broken out in two displays, namely by life cycle cost phase (e.g., DDT&E, production and operation) and by the type of activity, e.g., traffic through the station, orbiter-only (no station participation) flights, and finally, high inclination flights through VAFB. The results of this analysis led to the recommendation to pursue Option 3 (the minimum cost option), the current growth eight-man station at low (28°) inclination.

OPTION COST COMPARISON, SCENARIOS 6 AND 6A; LOW, MEDIUM, AND HIGH TRAFFIC MODELS

Figure 1-23 shows the cost comparison for both the Space Station (Option 3) and orbiter-only (Option 5) operation for two mission scenarios and three traffic levels. This figure allows a comparison of the cost implications induced by increments in either traffic level, accommodation mode (options), or both.

Comparison of the two options in a given mission scenario and traffic level allows one to determine the cost associated with a change in accommodation (Space Station or orbiter-only) to achieve a given level of performance (determined by mission scenario and traffic level). Note that the Space Station option cost is lower than the orbiter-only option for all traffic levels in Scenario 6.

Comparison of traffic levels for a given mission and option allows one to determine the cost associated with a change in the level of performance (for a given mode of accommodation).

Scenario 6 is a Space-Station-oriented mission model. Because it is unlikely that the orbiter-only option would attempt to accommodate this higher level of performance, Mission Scenario 6A was formulated. Scenario 6A is orbiter-only oriented and provides a more realistic Option 5 Cost. Care, however, must be used in cost comparisons of the Space Station option of Scenario 6 with the orbiter-only Scenario 6A. While Option 5 of Scenario 6A has a

Table 1-18. Program Options Definition

SPACE STATION				OTHER ELEMENTS			
			LOCATION	STS PERFORMANCE			
OPTION	FUNCTIONS	SIZE	ALT/INCL	STD (LB)	SCAVENGE	OTV	TMS
1	HIGH-ENERGY MISSION STAGING	4-MAN	200 NMI 28.5°	61,000	8,000	SPACE-BASED REUSABLE SINGLE-STAGE CRYOGENIC	GROUND & SPACE BASED REUSABLE BI-PROPELLANT
2	SPACE PROCESSING MISSION SUPPORT	4-MAN	200 NMI 28.5°	61,000	—	PAM A&D IUS IUS FIRST STAGE CENTAUR F&G	GROUND & SPACE BASED REUSABLE BI-PROPELLANT
3	MULTIPLE MISSION SUPPORT	4-MAN 8-MAN	200 NMI 28.5°	61,000	8,000	SAME AS OPTION 1	SAME AS OPTION 2
4	SPACE PROCESSING & SCIENCE & APPLICATIONS MISSION SUPPORT	4-MAN	200 57°	47,500	—	SAME AS OPTION 2	SAME AS OPTION 2
5	NO SPACE STATION		160 NMI 28.5° 57° 98°	70,000 49,000 25,000	— — —	PAM A&D IUS IUS FIRST STAGE CENTAUR F&G	GROUND-BASED REUSABLE BI-PROPELLANT
6	TWO SMALL MULTIFUNCTIONAL STATIONS	4-MAN 4-MAN	200 NMI 28.5° 57°	61,000 47,500	8,000 8,000	SAME AS OPTION 1	SAME AS OPTION 2

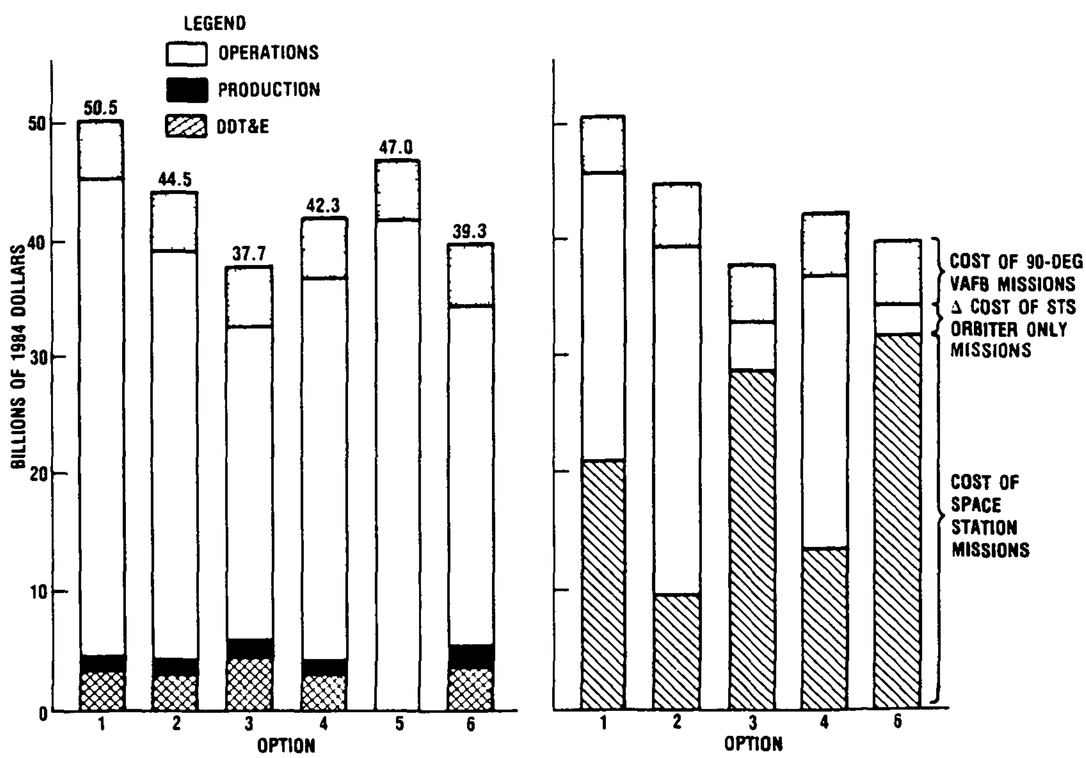


Figure 1-22. Option Cost Comparison, Scenario 4

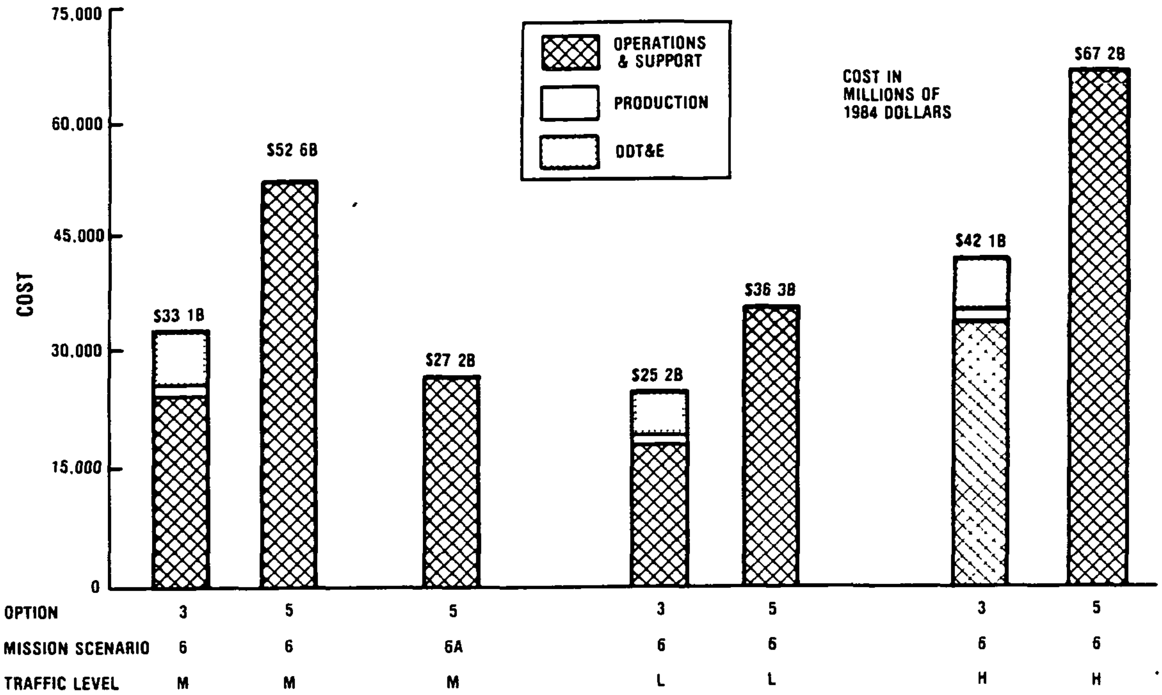


Figure 1-23. Option Cost Comparison, Scenarios 6 and 6A

lower total cost than Option 3 of Scenario 6, it also has a significantly lower level of performance (e.g., minimal space materials processing, less ambitious commercial communications, etc.).

WHO PAYS ANALYSIS AND COMPARISON, SCENARIOS 6 AND 6A; OPTIONS 3 AND 5

While total overall option costs are important for comparisons, it is also important to examine what level of cost each user category would bear. Therefore, analyses were undertaken to determine the overall system level cost impact of capability increments for the various user categories, e.g. DOD, NASA and other government, space processing, and commercial communications.

Figure 1-24 shows the results of this "who pays" analysis for the 1991 to 2000 time frame. The pie charts allow one to compare how each option is allocated to its user categories, and the bar chart reveals option cost comparisons by user. Note that the Shuttle-only option of Scenario 6 would require acquisition of three extra orbiters and appropriate ground facilities to accommodate the high launch rate (approximately 55 flights per year).

Because the reusable OTV is not available at the Space Station until 1994, the "who pays" analysis was split into two timeframes: 1991-1993 (Figure 1-25) and 1994-2000 (Figure 1-26). This allows one to more completely understand the effect of OTV availability on the user category costs. Notice that in the earlier timeframe the Space Station slightly dominates the orbiter-only option for Scenario 6, but in the steady-state timeframe (1994-2000) cost savings associated with the Space Station option are greatly enhanced.

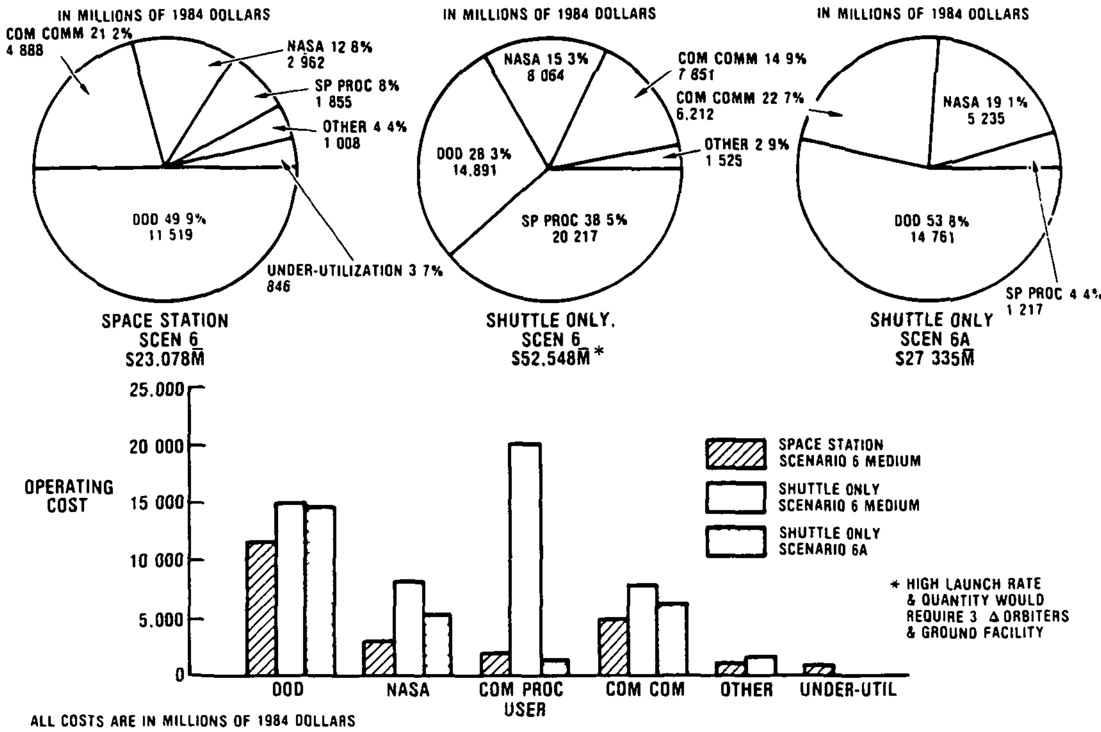


Figure 1-24. Who Pays Analysis--Scenarios 6 and 6A, Option 3 Versus 5

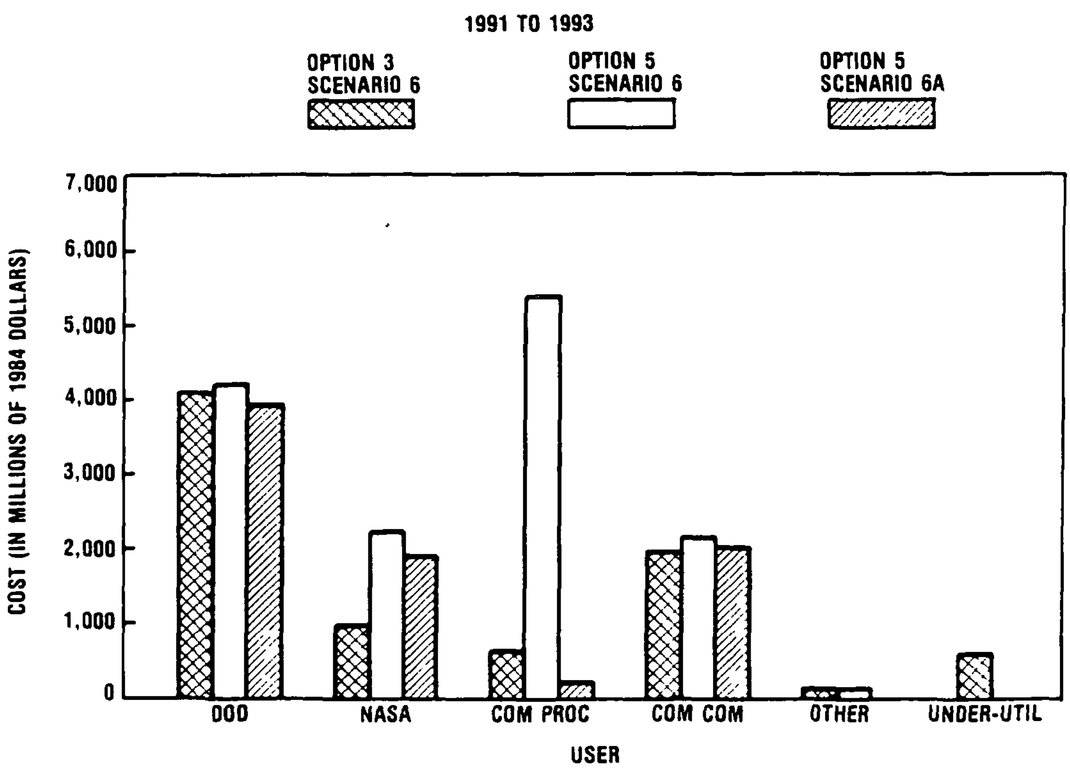


Figure 1-25. Who Pays Option Comparison--1991 to 1993

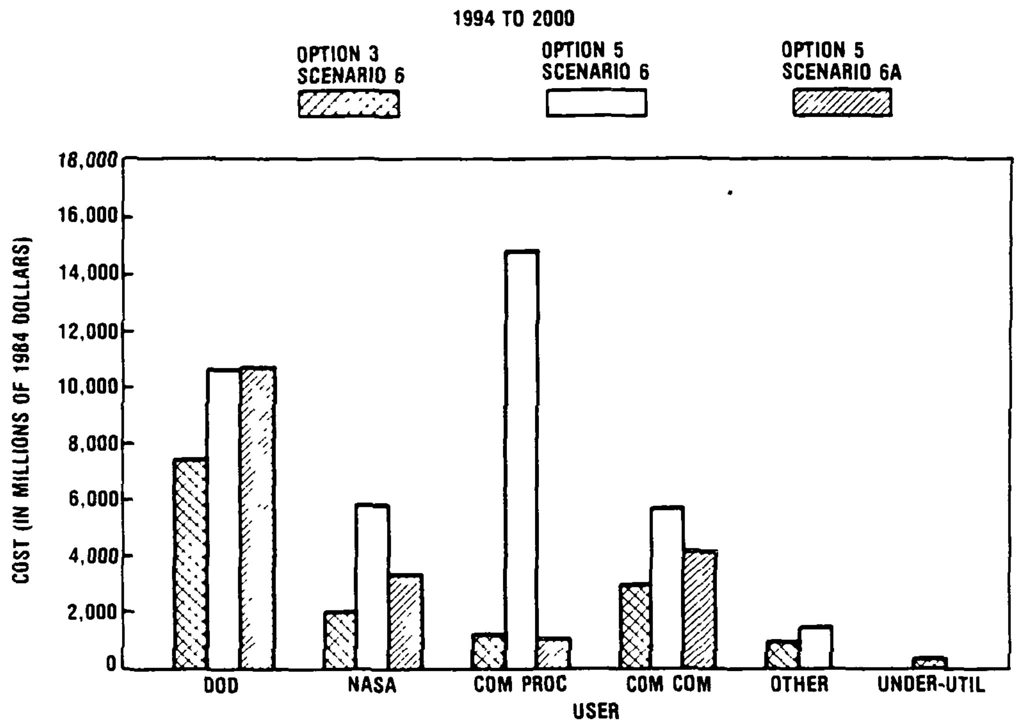


Figure 1-26. Who Pays Option Comparison--1994 to 2000

USER COST ALLOCATION METHODOLOGY

For the "who pays" analysis, distinct types of allocation criteria were used to distribute the SOS program resources to the user categories. The primary criteria utilized are:

Resource	Allocation Criteria
Shuttle flights	User equivalent flights
Space Station costs	User man-hour requirements
OTV costs	User utilization
OTV propellant costs	User utilizations

A program for allocation of Shuttle flight costs to users was devised by means of a concept called equivalent flights. Since the Shuttle cargo bay can accommodate more than one payload, a method was devised to allocate the entire launch cost proportionately to each user.

Equivalent flights for each user category were determined by year by dividing the cargo mass to orbit for each user by the total cargo mass to orbit and multiplying by the number of manifested flights that year. This methodology assures that all flight costs are allocated (i.e., the sum of the equivalent flights over all the users equals the number of manifested flights). A summary of this analysis is given in Table 1-19, with greater detail shown in Tables 1-20 and 1-21.

Table 1-19. STS Equivalent Flights

	EQUIVALENT STS FLTS (SCENARIO 6, MEDIUM MODEL)	
	SPACE STATION	SHUTTLE ONLY
• COMMERCIAL COMMUNICATIONS	34.4	75.8
• COMMERCIAL PROCESSING	16.2	203.6
• DOD	109.0	158.7
• NASA & OTHER CIVIL GOVT	27.6	96.8
• SPACE STATION RELATED	24.8	0
• ASSEMBLY	(7.1)	
• LOGISTICS	(3.0)	
• DOCKING MODULE	(14.7)	
• OTV RELATED	53.6	0
• OTHER	7.4	15.1
TOTAL FLIGHTS	273.0	550.0

A computer model was used to determine OTV and propellent requirements for each user category to meet the mission model requirements. The results are shown in Table 1-22.

User man-hour requirements were forecast to meet the needs of the mission model (see Table 1-23). Space Station production and operations costs were allocated by the proportion of user man-hours to the total available man-hours.

Table 1-20. Equivalent STS Flights--Space Station

Space Station

User	Inclination *Low*	*Med*	*High*	*Total*
Commercial Communications	34.4	-	-	34.4
Commercial Processing	16.0	-	-	16.0
DOD	43.6	24.6	40.8	109.0
NASA and other civil government	16.2	1.4	10.0	27.6
NASA planetary	(1.8)			(1.8)
NASA astrophysics	(7.1)	(1.4)		(8.5)
NASA life sciences	(1.1)			(1.1)
NASA resources	(0.1)		(6.8)	(6.9)
NASA environmental	(0.1)		(0.8)	(0.9)
NASA processing	(0.5)			(0.5)
NASA communications	(1.3)			(1.3)
NASA technology	(2.0)			(2.0)
Government environmental	(2.2)		(2.4)	(4.6)
Space Station related	24.8			24.8
Assembly	(7.1)			(7.1)
Logistics	(3.0)			(3.0)
Docking module	(14.7)			(14.7)
OTV related	53.6			53.6
Upper stage assembly	(0.7)			(0.7)
Upper stage log	(4.0)			(4.0)
Topoff tank	(5.4)			(5.4)
Topoff fuel	(28.9)			(28.9)
Scavenged fuel	(14.8)			(14.8)
Other	3.2		4.2	7.4
Communication resource observation	(0.2)		(4.2)	(4.4)
Communication environmental observation				
Foreign enviornmental				
GEO servicing	(3.0)			(3.0)
Total	192.0	26.0	55.0	273.0

Table 1-21. *Equivalent STS Flights--Shuttle Only*

Shuttle Only

User	Inclination			
	Low	Med	High	Total
Commercial communications	75.8			75.8
Commercial processing	203.6			203.6
DOD	57.2	60.7	40.8	158.7
NASA and other civil government	23.5	63.3	10.0	96.8
NASA planetary	(7.3)			(7.3)
NASA astrophysics	(8.1)	(63.2)		(71.3)
NASA life sciences	(0.2)			(0.2)
NASA resources			(6.8)	(6.8)
NASA environmental	(0.1)	(0.1)	(0.8)	(1.0)
NASA processing				
NASA communications	(1.3)			(1.3)
NASA technology	(2.8)			(2.8)
Government environmental	(3.8)		(2.4)	(6.2)
Space Station related	NA	NA	NA	NA
Assembly				
Logistics				
Docking module				
OTV related	NA	NA	NA	NA
Upper stage assembly				
Upper stage log				
Topoff tank				
Topoff fuel				
Scavenged fuel				
Other	10.9		4.2	15.1
Communication resource observation	(0.7)		(4.2)	(4.9)
Communication environmental observation	(10.2)			(10.2)
GEO servicing				
Total	371.0	124.0	55.0	550.0

Table 1-22. Space Station OVT Usage and Propellant Data Used in "Who Pays" Allocation

USER CATEGORY	NO. OF OTV FLIGHTS	%	CRYO PROPELLANTS UTILIZED — KLBS	%
DOD	36.3	46.5 %	1317.0	47.3 %
COMMERCIAL COMMUNICATIONS	25.2	32.3	916.0	32.9
SCIENCE & APP/ PLANETARY	4.8	6.2	166.0	6.0
OTHER SCIENCE & APP	5.4	6.9	124.0	4.5
GEO SERVICING	6.3	8.1	260.0	9.3
TOTAL	78.0	100.0	2783.0	100.0

Table 1-23. Space Station Man-Hours Used in "Who Pays" Analysis

USER CATEGORY	TOTAL MAN-HRS	PROPORTION
COMMERCIAL COMMUNICATIONS	20,916	.098
COMMERCIAL PROCESSING	56,359	.266
DOD	31,632	.149
NASA	32,428	.153
OTHERS	5,266	.025
STATION OPERATIONS	31,200	.147
HOURS NOT UTILIZED	34,359	.162
TOTAL	212,160	

SCHEDULE IMPACT ANALYSIS

Figure 1-27 summarizes a schedule trade analysis that was performed for 1991, 1993, 1994, and 1995 growth station and OTV initial operational capability (IOC) dates. It was assumed that evolution from the initial four-man station to the eight-man station will occur simultaneously with the OTV IOC.

Costs shown in this figure are DDT&E plus production and were time phased using the same rationale described earlier. Figure 1-28 details time-phased DDT&E and production costs for each of the four cases considered.

In Figure 1-29, we have plotted the peak around expenditure rate versus IOC year to indicate the effect of design to annual budget. To minimize (optimize) the effect of peak annual expenditure, a preferred IOC date of 1994 is indicated.

From the potential users' point of view, however, an earlier OTV IOC date would be preferred as illustrated in Figure 1-30 where the increased cost of high energy orbit transportation is delineated as a function of the IOC data. Estimated percent cost increase levels for 1992, 1993, 1994, and 1995 delays are 6, 14, 21, and 31 percent, respectively.

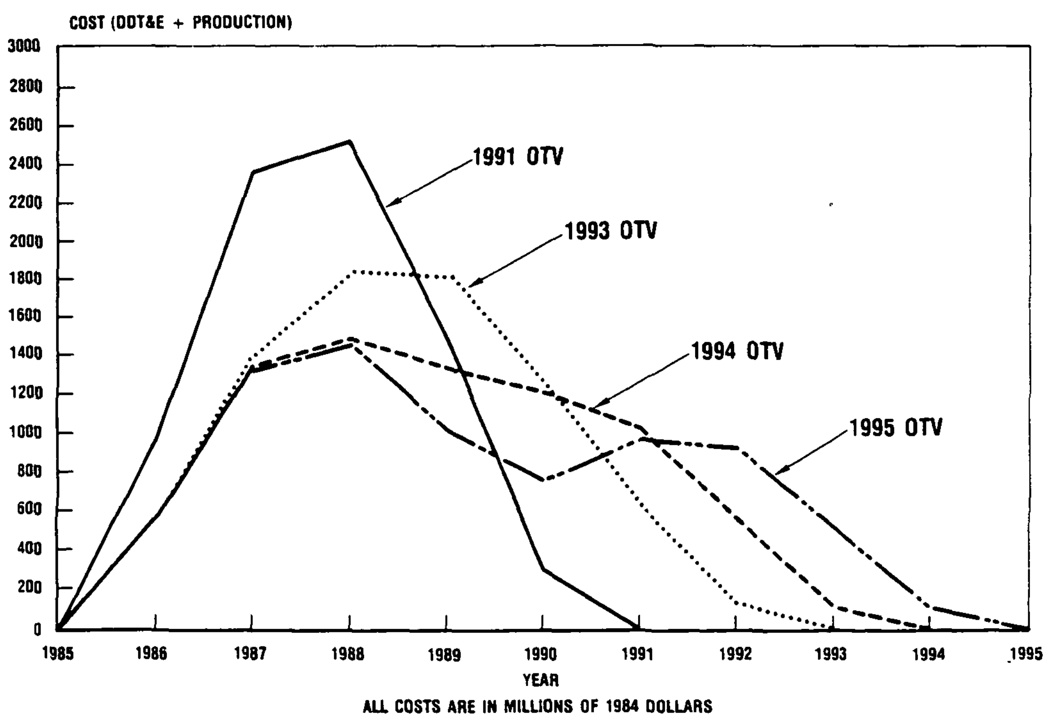


Figure 1-27. Space Station/OTV Schedule Trade Analysis

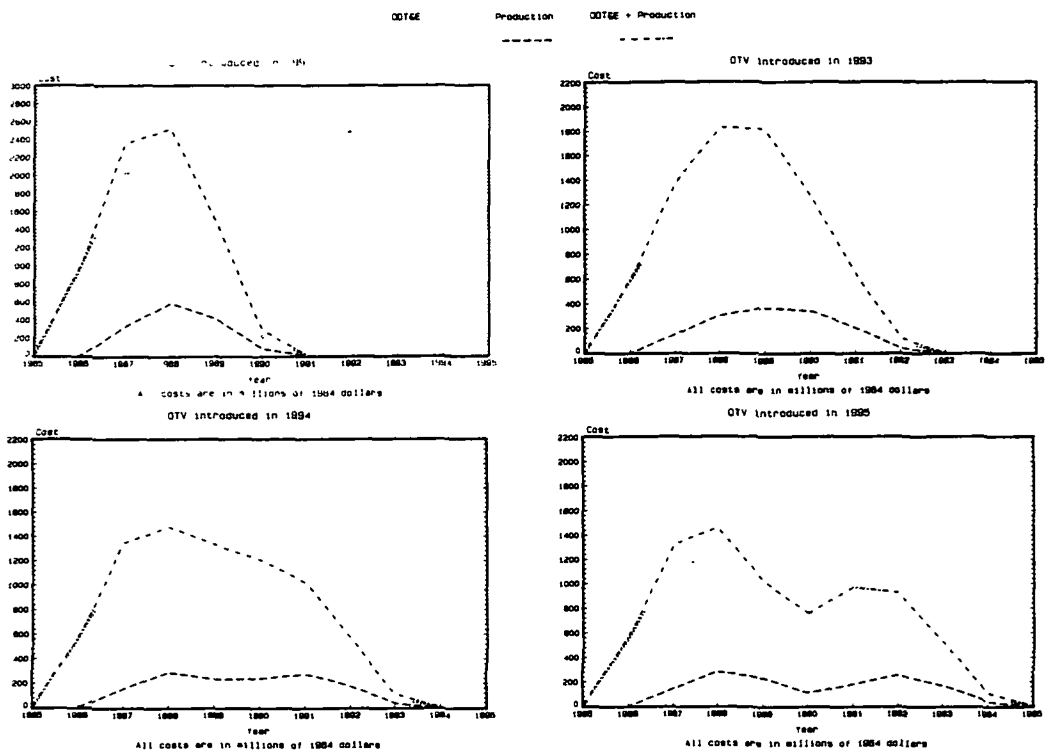


Figure 1-28. Space Station Growth Configuration Program Cost Expenditure (by Year by Varying IOC Date)

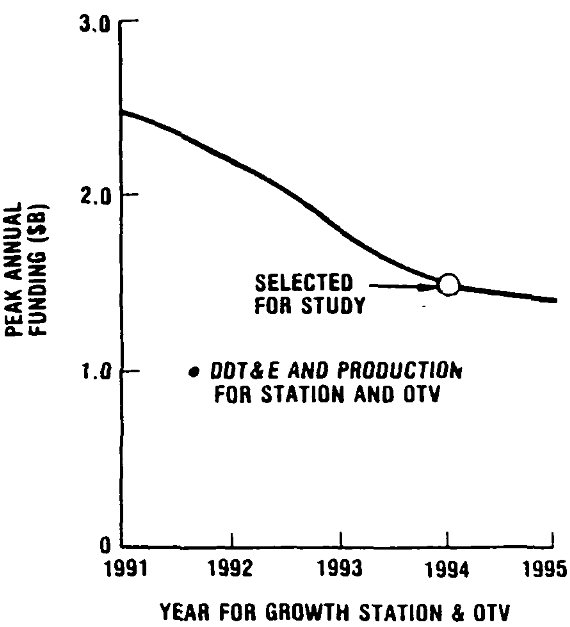


Figure 1-29. IOC Timing Effect on Program Peak Annual Funding

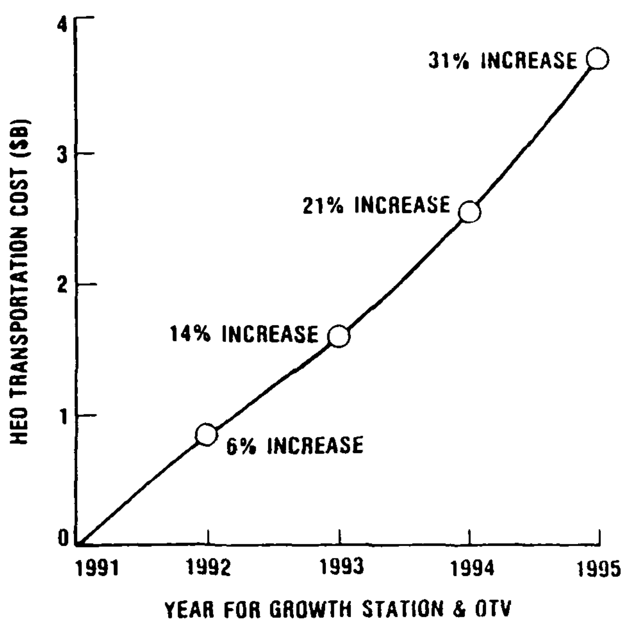


Figure 1-30. IOC Timing Effect on User HEO Transportation Cost

COST EFFECTIVENESS COMPARISONS

A series of mission cost comparisons were conducted of orbiter-only versus the Space Station mode of mission accommodation. Missions selected include the spectrum of various user categories.

An estimated set of Space Station service prices were developed in order to determine the cost effectiveness of utilizing the Space Station. The primary services identified are the provision of crew hours, energy, storage, pressurized port usage, and the use of the OTV service facility. In Table 1-24, the values assessed are indicated, as well as a summary of which station cost element is allocated to the service. The costs included in the pricing policy are the module production costs written off over a 20-year period and recurring Space Station operation costs. The price factors include the allowance for 20 percent utilization factor. These data are utilized, where appropriate, in the mission cost comparisons that follow.

ATTACHED SCIENCE SIRTF COST COMPARISON

Figure 1-31 illustrates the economic comparison of conducting experiments using the Shuttle Infrared Telescope Facility (SIRTF), which accommodates photometric, spectroscopic, and polarimetric instruments. Mission cost comparison totals and cost per day of exposure (performance comparison of 246 days exposure) are shown here along with the technical input to the cost estimate. The Space Station operation indicates a cost advantage varying from 8:1 to 14:1 depending upon the capability of an extended duration orbiter to perform the equivalent mission level.

SPACE PROCESSING

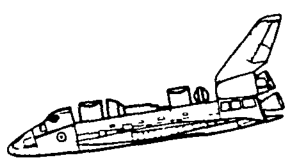
In Figures 1-32 and 1-33, cost comparisons are set forth for a space processing attached laboratory (research) and an attached pharmaceutical production factory, respectively. Cost comparisons are conducted at equal effectiveness or output levels. Space Station cost advantages and user profitability are underscored. Mission characteristics and accommodation mode requirements for the station and no station case are set forth.

COMMERCIAL COMMUNICATIONS

Figure 1-34 provides a mission cost comparison of transportation systems (orbiter versus Space Station) accommodating a spectrum of commercial communication spacecraft payload levels as indicated. Table 1-25 provides a further transportation cost comparison of spacecraft in the 12,000-pound category.

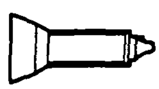
Table 1-24. Space Station Services Pricing Policy

SPACE STATION SERVICE	SERVICE CHARGE POLICY (FY'84 $)	STATION COST ELEMENT ALLOCATED TO SERVICE							
		CMND MOD	ENERGY MOD	HABIT MOD	TUNNEL MOD	LOGIS MOD	AIRLOCK MOD	PSM MOD	PROP TANK
• CREW HOURS	$14,570/CREW HOUR	✓		✓	✓	✓	✓		
• ENERGY	$8,845/KW-DAY		✓			✓			
• PAYLOAD SUPPORT MODULE STORAGE	$886/FT/DAY	✓				✓		✓	
• PRESSURIZED PORT USAGE	$42,381/DAY	✓			✓	✓			
• OTV SERVICE FACILITY	$1.66 MILLION/MISSION	✓						✓	✓



EXTENDED-DURATION ORBITER

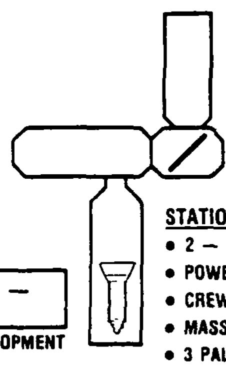
- SHARED FLIGHTS (50%)
- EDO MISSIONS — 246 DAYS
  - 15 DAY — 20 MISSIONS
  - 30 DAY — 9.1 MISSIONS
  - 45 DAY — 5 8 MISSIONS



- SIRTF PAYLOAD
- 5500 LB EQUIP PLUS 74 LB CRYO/DAY
- 24 FEET

PERFORMANCE COMPARISON — 246 DAYS EXPOSURE

COSTS INCLUDED AMORITIZED DEVELOPMENT PLUS OPERATION
C/F = $77M̄



STATION

- 2 — 123-DAY CYCLES
- POWER — 1 kW/DAY
- CREW — 2 HOUR/DAY
- MASS — 16,000 + 9,000 LB
- 3 PALLETS

STS SYSTEM

	15 DAY	30 DAY	45 DAY
• TIME TO PERFORM EXPOSURE	~ 3 YR	~ 2 YR	~ 1 YR
• MISSION COSTS	$1,292M̄	$887M̄	$747M̄
• RATE — COST/DAY	$5.25M̄/DAY	$3.61M̄/DAY	$3.04M̄/DAY

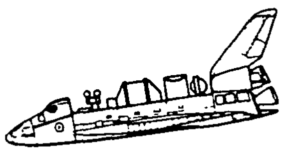
COST COMPARISON		
EDO / STATION	15 DAY	14.0
	30 DAY	9.6
	45 DAY	8.1

STATION SYSTEM

• TIME TO PERFORM EXPOSURE	~ 9 MONTH
• TRANSPORTATION	$39M̄
• STATION CHARGES: • POWER — 3.8M̄ • CREW — 6.0 • PSM — 43.7	53.5
	$92 5
• RATE — COST/DAY	.376M̄ $/DAY

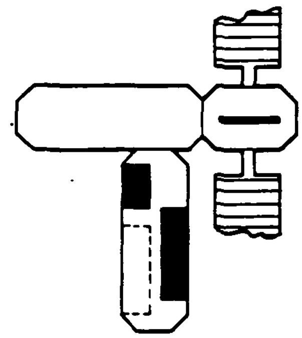
Figure 1-31. Attached Science Mission--SIRTF--1992 (1984 $M̄)

(1984 $M)



PHARMACEUTICAL LAB
- 5000 LB EQUIPMENT
- CYCLE — 15 HR AT 4 kW —
  — 9 HRS CREW
- 8 LB SUPPLIES/CYCLE

CRYSTAL LAB
- 2550 LB EQUIP
- CYCLE — 2 HR AT 3 kW —
  — 3 HRS — CREW
- 11 LBS SUPPLIES/CYCLE



STS ACCOMMODATION
- SHARED FLIGHT (75%)
- NO EXPT CYCLES

PERFORMANCE COMPARISON AT SEVERAL FIXED EXPERIMENT CYCLES

- EQUIPMENT IN SHARED MODULE

EDO	MISSION HOURS	NO CYCLES
15	360	24
30	720	48
45	1080	72

	15 DAY	30 DAY	45 DAY
• MASS (LB)	7956	8462	8918
• CREW — HRS	288	576	864
• LAB UTIL	241	257	271

STS SYSTEM

	15 DAY	30 DAY	45 DAY
• MISSION COSTS	$107M	$140M	$170M
• CYCLES	24	48	72
• $/CYCLE	$4.45M	$2 91M	$2 35M

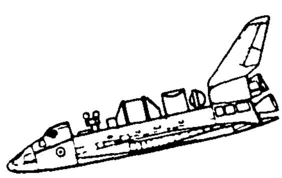
STATION SYSTEM

	15 DAY	30 DAY	45 DAY
• MISSION COSTS	$20M	$30M	$40M
• CYCLES	24	48	72
• $/CYCLE	$ 82M	$ 625M	$.559M

EDO	15	30	45
• STATION RATIO	5 4	4 6	4 2

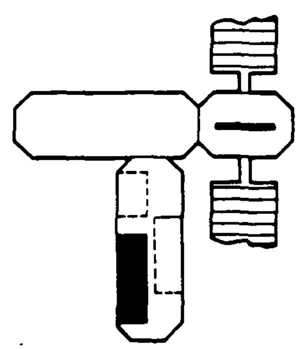
Figure 1-32. Space Processing Research--1991 (1984 $M)

(1984 $M)



COMPARISON AT FIXED DEMAND 50 LBS

PHARM PRODUCTION SYSTEMS:
- PROD EQUIP = 12,200 LB
- POWER = 4 kW
- DUTY CYCLE (PROD. RUN) = 40 HR
- CREW HOURS/CYCLE = 8 HR
- RAW MATERIAL = $7M/LB
- PRODUCT VALUE = $17.5M/LB



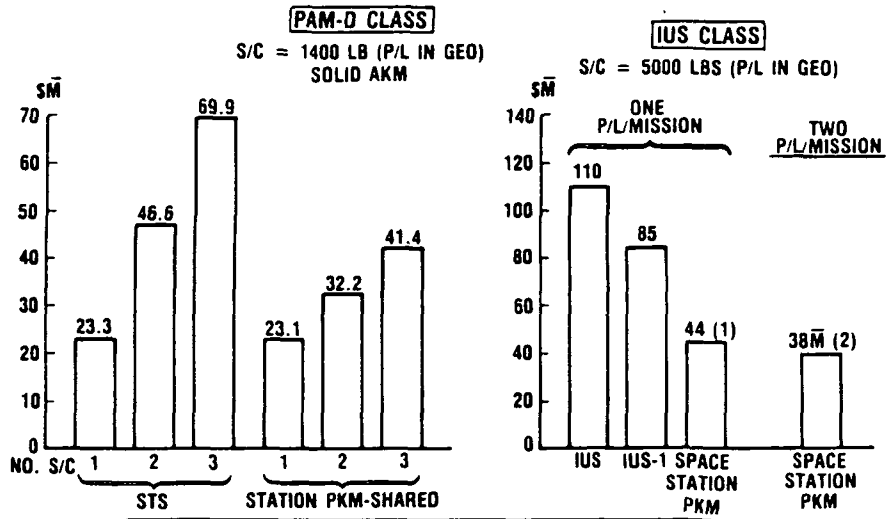
EDO + SPACE-LAB
- SHARED MISSION (75%)
- EDO

EDO	PROD. CYCLE/ MISSION	NO. OF MISSIONS
15	9	5 6
30	18	2.8
45	27	1 9

STATION ACCOMMODATION
- OPERATING TIME = 2000 HR
  = 83 DAYS

SYSTEM	15-DAY EDO	30-DAY EDO	45-DAY EDO	STATION
• MISSION COSTS — FOR 50 LB	$641M	$419M	$340M	$49M
• $/LB —	$11 9M/LB	$7.8M/LB	$6 3M/LB	$.99M/LB
• TOTAL PRODUCTION $/LB	$18.9M/LB	$14 8M/LB	$13.3M/LB	$8.0M/LB
• REVENUE/LB/YR	— (NEGATIVE)	$2.74M/LB	$4 24M/LB	$9.51M/LB
• PRODUCTION TIME — MONTHS	10	5	5	3

Figure 1-33. User Costs--Space Processing Production--1994 (1984 $M)



STS TIME-PHASED COST — S/C = 1400 LB		
1985	— PRICE POLICY	$16.1M
1988	— PRICE POLICY	24.1M
1991	LOW FORECAST	23.3M
	HIGH FORECAST	29.7M

Figure 1-34. Small Communication Satellite Operations Cost (1984 $M)

SERVICING AT GEO AND LEO

Figure 1-35 illustrates orbiter-only versus Space Station accommodation of servicing missions at LEO and GEO. Cost comparisons are shown for servicing four to eight satellites at LEO and from one to three satellites at GEO. Estimated Space Station advantages are indicated.

Table 1-25. Mission Cost--Large GEO Transportation--1991

12,000-POUND CLASS PAYLOAD
(1984 $ M)

40 FLIGHTS/YEAR AT $77M/FLIGHT

	STS EXPENDABLE CENTAUR		SPACE-BASED REUSABLE PKM
	G	F	12,000-LB DESIGN
PERFORMANCE:			
WG	46,600 LB	65,000 LB	53,244 LB
WP/L (GEO)	10,600 LB	13,600 LB	12,000 LB
LENGTH	23 FEET	33 FEET	
MINIMUM COST	($M)		($M)
STS AT 40 FLTS/YR	$ 77	$ 77	60.3
STAGE COST	41	39	5.0
REUSABLE OTV USE	—	—	1.35
STATION CREW	—	—	7.7
TOTAL	$118	$116	$74.3M
$/LB	$11,132	$8,529	$6,191/LB

36% REDUCTION

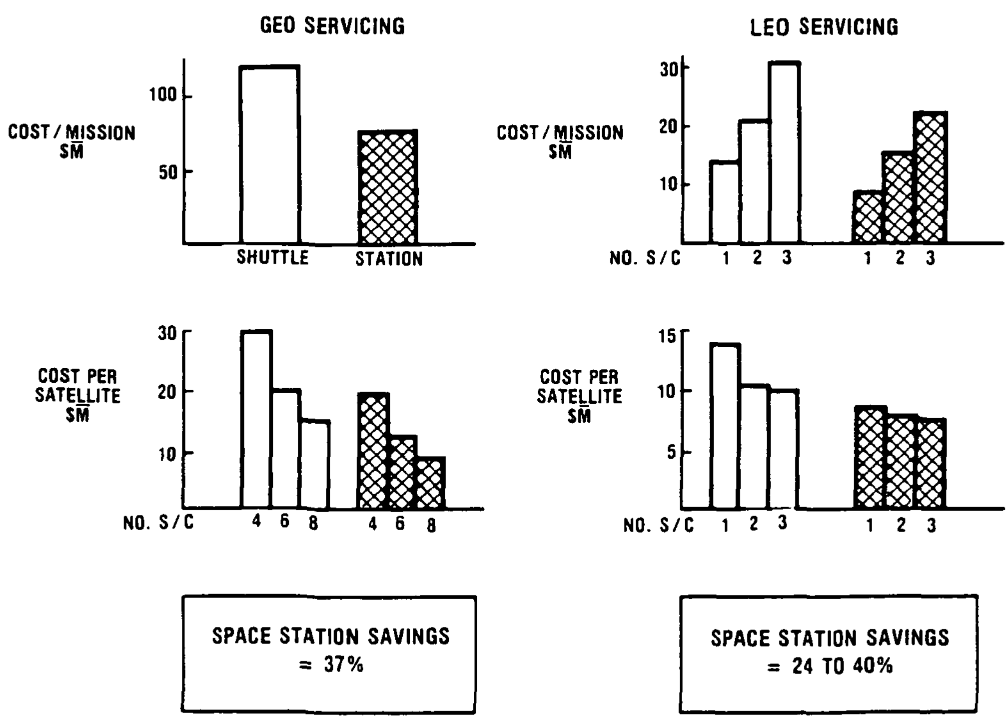


Figure 1-35. Servicing Cost Comparison at LEO and GEO

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2.0 BENEFITS ANALYSIS

THE IMPORTANCE OF PERFORMING A BENEFITS ANALYSIS

"It has nothing to do directly with defending our country except to help make it worth defending."

Dr. Robert Wilson, testifying on the value of a particle accelerator

Before a major commitment of federal funds can be made to implement a program, a rigorous assessment of the benefits accruing to the nation from the program must be prepared. Without an analysis of a program's potential benefits, the Administration and Congress would be ill-equipped to make a determination as to which of the many competing demands placed on the federal budget deserve funding and the taxpayers would be denied the main tool for assessing whether the proper choice was made.

A benefits analysis translates data into values so that Congress and the public can weigh the results and compare them against what the alternatives have to offer. It not only defines the value of a program to the nation, but also clarifies the essential elements and objectives of the program to those who are in the process of designing it so that the program can achieve its full potential.

As part of the Space Station Needs, Attributes, and Architectural Options contract, Rockwell was assigned the task to "define where possible the economic, performance, and social benefits which accrue from the various [Space Station] mission alternatives." The following is a discussion of the approach, methodology, and results of the analysis.

APPROACH

The following approach has been used in determining and quantifying benefits:

- The benefits that can be attributed to the Space Station are the delta benefits between Mission Scenario 6 (with Station) and Mission Scenario 6A (no Space Station).

- Benefits arising from the conduct of specified missions that use the Space Station should be quantified into dollar values, however approximate the methodology may be. This is necessary in order to assist the NASA, and hence the total democratic process of the country, to determine how worthy a Space Station program is.

- The methodology, assumptions, and the numerical values used should be fully explained and documented so that a reader who wishes to change the assumptions or inputs can readily do so and see the results of the changes.

- The benefits arising from each of the five mission areas (science and applications, space processing, etc.) should be calculated separately so as to make visible the relative benefits from each area and so allow changes in emphasis in future work on Space Station. Wherever possible, subcategories should be broken out within each area to give further insight as to where and how the benefits are generated.

- The value of the benefits in each case should be calculated as: (1) benefits to the user (i.e., the firms, agencies, or industries that are direct users of the Space Station), and (2) benefits to the nation as a whole (i.e., the summed value gained by each member of the United States population as the benefits cascade through society from the Space Station user to the individual citizen).

- The dollar value of the benefits which are going to occur in the 1991 to 2000 time period and beyond should be converted to present day value by using well-known discounting techniques. We have chosen 1986, the year we are assuming a go-ahead decision on Space Station will have to be made, as the present value year, and we have used a 10 percent discount rate (the value generally accepted currently for government decisions). This means that benefits occurring in future years are reduced by multiplying by a factor of 0.9 for each year beyond 1986.

- Constant 1984 dollars have been used in all calculations, thus eliminating issues relating to future inflation rates.

- Besides the benefits arising from the Space Station by virtue of the specific missions we have identified in Mission Scenarios 6 and 6A, there are a number of broader benefits arising from the Space Station independent of what missions it performs. These have been identified and described, but no attempt was made to assign dollar values to these benefits as the benefits are closely related to national policy rather than to economic value. Instead, these non-quantifiable benefits have been related to the President's space policy goals announced July 4, 1982, and we show how these benefits contribute to the goals.

- It is noted that quantifiable benefits fall into two categories: cost savings/cost avoidance and value obtained from doing missions not otherwise possible. These sets of benefits should be summarized separately.

- Finally, the ultimate purpose of determining the benefits is to compare them to the costs of undertaking the Space Station program, in order for the country to decide if it wants to do so. At the conclusion of this section on benefits, the following comparison is presented:

  1. The dollar value of the quantifiable benefits to the nation, discounted to 1986 present day value, attributable to the Space Station.

2. The investment, in dollars discounted to 1986 present day values, that must be made by the U.S. government to achieve these benefits.

METHODOLOGY

Most of the methods used in determining the dollar value of the quantifiable benefits are described in the individual sections that follow and are self-explanatory. A few techniques, however, are common to all of these sections and need discussion and explanation.

First, we must explain what is meant by the value of a benefit. If a person buys an item for $100 and sells it for $120, the value of the benefit is clear cut--$20. If the person spends $100 and receives a painting which he likes, or spends a day skiing at a mountain resort, it is clear that he has received a benefit, but the dollar value of this benefit is not so clear. Obviously, he values the picture or the skiing at more than $100; otherwise, he would not have spent the money.

Similarly, if a firm or a government agency spends a million dollars on some investment, they are receiving a benefit which they value at more than a million dollars--considerably more if it is a good investment. The value of the benefit may be relatively easily quantifiable by an accountant, economist, or director of business development in the case of a predictable business venture; or by a government official, policy maker, or by our budgetary process in the case of a government project. In many cases, however, such as the situation we are in here, the value of the benefit is difficult, if not impossible, to estimate with any percision.

We have relied here on the following arguments brought forward by our staff economists. For a new project to be economically viable, i.e., to be able to compete against other projects in an open market, the present day value of the estimated future income must be at least five times the present day value of the expected investment. One way of explaining this is to point out that a businessman or a firm that makes an investment of one million dollars in a new enterprise expects that, within a few years (three to five in the United States and longer in some other countries), this enterprise can be sold or will be worth about five million dollars. In practice, this is an average figure, which in happy circumstances is exceeded and in many other cases is not reached.

A more precise definition of this idea is shown in Figure 2-1. The broken lines show, schematically, the expected annual investment and the expected annual profit over a period of years. The solid lines show the discounted values of these (representing the commercial factoring-in of the cost of money). The hatched areas then represent the present day value, at the start of the project, of the total investment and total earnings value of the project. A good investment is one where the profit cross-hatched area is at least five times the investment cross-hatched area.

On the advice of our economists we have used this is as our criteria for determining the value of an investment, both for commercial and for government projects. Since the net benefit is the value of the profits minus the cost of the initial investment, the value becomes:

VALUE = 4 X INVESTMENT OR COST OF THE PROJECT

This rule applies to the value of the benefit to the initial investor. In our case, this is who we call the Space Station user (i.e., the initial investor in, let us say, a spacecraft) who is also the agent who contracts with the NASA to use the Space Station services or Space Station related services such as the OTV or TMS.

The benefits of this very same spacecraft are passed on as benefits to a whole string of subsequent users, each of whom expects to receive more value than money he pays out. This series is shown schematically in Figure 2-2 for a hypothetical educational program which uses this satellite.

Value flows in the direction of the arrows, while money (payments) flow in the opposite direction. We note that NASA, which is the medium for the government's investment in the Space Station, receives a reimbursement (i.e., no profit), whereas all the commercial firms in the chain receive net value in the form of profit. But in every case the ultimate beneficiary in the chain is a citizen whose net benefit is value received--an education in the case shown--and cannot be uniquely quantified in dollars.

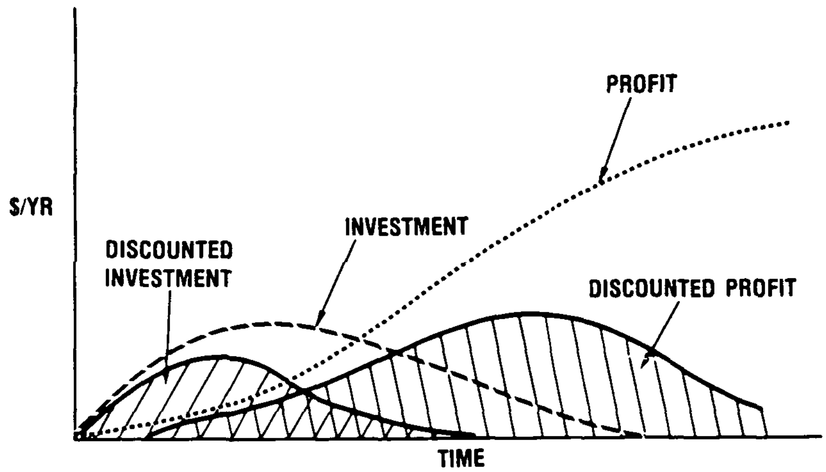
When multiplied and summed by the total of such benefits (education, security, health, etc.) received by the nation's citizenry, this becomes the benefit to the nation and, if quantified, it becomes the value of the benefit to the nation.

Thus, an investment by the government in the Space Station (through NASA) leads to an investment by and, hence, a resulting benefit to the user. The benefits are ultimately passed on to individuals in the United States or the nation.

We have elected in this study to estimate the value of the benefits to the user and to the nation, thus skipping the many potential intermediary beneficiaries. The advice we received from our economist is that the integrated value of the benefits to the nation can be calculated as:

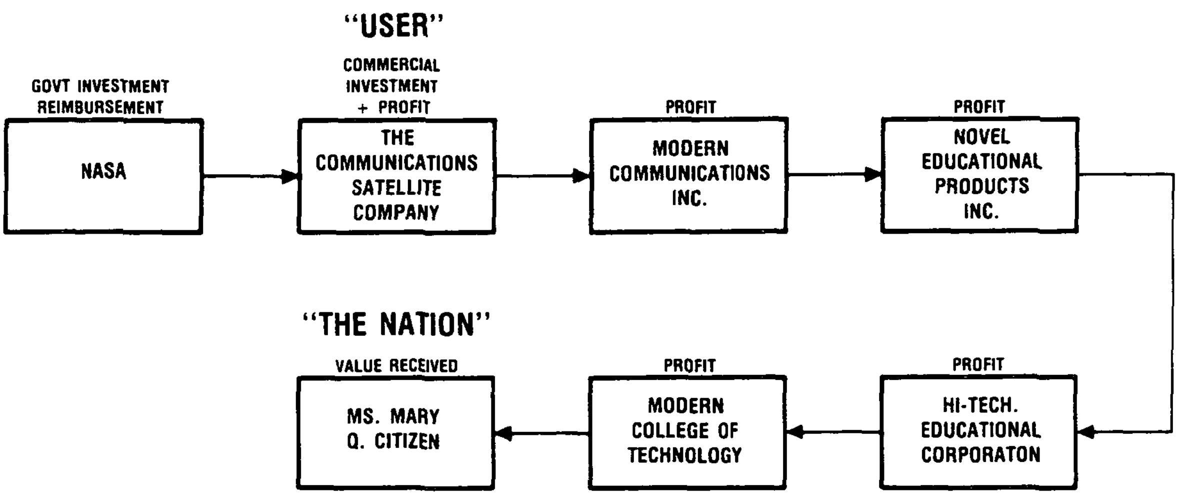
VALUE TO NATION = FACTOR X THE BENEFITS RECEIVED BY THE USER.

The factor to be used depends on the degree of risk, technology, and novelty of the project, and should vary from three to six. These factors can be justified by the table (shown in Figure 2-2) which shows a typical chain of six steps between the first investor and the ultimate beneficiary (i.e., between the user and the nation) each of whom typically expects a profit or increase in benefits between 20 percent and 35 percent depending on the factors just described. We have used our best judgment to determine the appropriate factors in each individual benefit area.



- **DISCOUNTED PROFIT ⩾ 5 × DISCOUNTED INVESTMENT**
- **VALUE TO USER ⩾ 4 × INVESTMENT**
  - **10% DISCOUNT RATE**
  - **1986 PRESENT DAY VALUE**

Figure 2-1. Present-Day Value of Investment and Profit



TYPE OF VENTURE	PROFIT PER STEP	NUMBER OF STEPS	OVERALL INCREASE
LOW RISK, HAS BEEN DONE BEFORE	20%	6	3
HIGH RISK, NEW TECHNOLOGY, HAS NOT BEEN DONE BEFORE	35%	6	6

Figure 2-2. The Benefits Chain--Value to the Nation

QUANTIFIABLE BENEFITS

This section describes results of our analyses on the quantifiable benefits resulting from each of the five mission areas:

- Science and Applications
- Commercial space processing
- Commercial communications
- National security
- Space technology

Each area is discussed separately, with the results summarized at the end of the section.

SCIENCE AND APPLICATIONS

The Science and Applications area comprises seven disciplines.

- Astrophysics
- Environmental
- Planetary
- Resource observation
- Life Sciences
- Space Processing
- Communications research

The benefits offered to each area by a Space Station fall within the following three categories:

- Lower transportation costs
- Reduced hardware DDT&E costs
- Value added by doing more missions.

The station's presence will reduce the transportation costs associated with performing each of the mission areas. A comparison of the flight manifests of Scenarios 6 and 6A shows that the Station's presence will save the science and applications community 36.6 equivalent Shuttle flights (from 69.4 Shuttle flights, to 32.8) during the ten year mission model period. At $77 million per flight, this amounts to a $2,818 million savings. Discounted to 1986 dollars (using a 10 percent discount factor), it translates to a savings of $1,122 million. Table 2-1 gives the breakdown of these Science and Applications transportation discounted costs per year for the two mission scenarios.

The availability of the Space Station will also result in some hardware development cost savings. The projected DDT&E for the System Z platform power module is $1.6 billion, with a first flight in 1992, without the Space Station. With the Space Station, the projected DDT&E is $0.26 billion with the first

flight in 1995. This is a difference of $1,34 billion. When discounted at 10 percent per year, starting in 1986, to 1992 and 1995 respectively, this difference becomes $480 million.

The value of the additional science and applications missions made possible by the Space Station was determined by estimating the value that each household in the U.S. would place on the additional missions to be performed due to Space Station. To do this, the U.S. was divided into five categories of households ranging from 10 percent of the households classified as space enthusiasts, to 10 percent classified as space funding opponents. An estimate of the additional value that would be attributed to the Space Station for each of the seven science and application disciplines by each household per category is shown in Table 2-2 in terms of $/yr/household. Although these estimates are judgmental, they are based on the results of many years of opinion polls commissioned by Rockwell International on how the U.S. public feels about the space program, or specific aspects of it. A general conclusion has been that there is a "silent majority" which gives support to space activities.

The average contribution of all the households, multiplied by the total number of households in 1986 (estimated at 120 million), and by the total number of years in the mission period (10 years), results in the value of the Space Station to the nation for each of the disciplines. In order to discount the total value to 1986 dollars, these are multiplied by an averaged discount factor of 0.3846 (i.e., $0.9^5 - 0.9^{15}$). This is the discounted value of the Space Station contributions to the totality of U.S. households--i.e., to the nation.

In order to estimate the value of these benefits to the Space Station users--i.e., to the science and applications community--we assumed that the applicable ratio between benefits to the nation and benefits to the user is 4.0, i.e., in the middle of the 3.0 to 6.0 range. We therefore obtained the benefits to the user by dividing the calculated benefits to the nation by 4.0.

The resulting benefits in the science and applications area are summed in Table 2-3. These amount to $3.2 billion to the users (the science and applications community), and $11.4 billion to the nation. The highest benefits arise from the reduction in transportation and DDT&E costs, and from the value of the additional mission capabilities, especially in the astrophysics and astronomy disciplines.

SPACE PROCESSING

Benefits in the space processing area occur from four categories:

- Lower mass transported to orbit, at lower cost per pound
- The value of additional experimentation
- The production of pharmaceuticals
- The production of crystals

*Table 2-1. Science and Applications Transportation Discounted Costs--Mission Scenario 6 Vs. 6A (1984 $M)**

	Year										Total
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Scenario 6	86	266	115	119	57	65	89	78	80	35	990
Scenario 6A	250	434	306	226	209	180	135	143	114	115	2,112
Cost Savings (6A)	164	168	191	107	152	115	46	65	34	80	1,122

*Based on $77 million per STS flight, 10 percent discount/year

Table 2-2. Delta Missions Value Distribution ($/Household/Year)

Missions	Percent					Average	Total House-Holds	Total Years	Total Discount Factor	Discounted Benefits ($M)**		
	10	25	30	25	10					To Nation		To User
Astrophysics	18	6.0	1.2	0.3	0	3.735				1,724		431
Environmental	6	2.0	0.5	0.1	0	1.28				590		148
Planetary	24	14.4	1.4	0.6	0	6.570				3,032		758
Resource observation	4	2.0	0.5	0.1	0	1.08	x 120M	x 10 yr	x 0.3846	498	÷ 4	124
Life science	5	2.0	0	0	0	1.00				462		115
Space processing	2	0.5	0.1	0.05	0	0.37				171		43
Communications research	1	0.5	0	0	0	0.22				102		26
Total						14.255				6,579		1,645

*Based on 120 million households in 1986
**10 percent discount rate; equivalent 1986 dollars

Table 2-3. Discounted Benefits for Science and Applications, $\bar{M}$ ('84)

Item	To Users	To Nation
• Lower transportation costs	1,122	3,366
• Less mission hardware DDT&E	480	1,440
• Value added		
• Astrophysics	431	1,724
• Environmental	148	590
• Planetary	758	3,032
• Resource observation	124	498
• Life science	115	462
• Space processing	43	171
• Comm research	26	102
Total	3,247	11,385

The first benefit, of transportation cost savings, turns out to be relatively small. We summarize the analysis in Table 2-4, which shows the masses transported in the 10 years 1991-2000 with and without a Space Station, and the corresponding transportation costs per pound.

Table 2-4. Masses Transported to LEO From 1991 to 2000 for Space Processing, and Transportation Costs

	Mass (lb)	Cost ($/lb)
With station	661,000	1,300
Without station	796,000	2,000

The resulting cost savings, discounted to 1986, are $65 millions to the users, and $195 million to the nation.

The Space Station also allows additional experimentation to be performed. This results from the decreased costs of on-orbit exposure time, and from the faster turn-around possible with a Space Station. Our mission models show the following annual expenditures (evenly spread out from 1991 - 2000).

- With Space Station - \$80 Million/yr
- Without Space Station - \$40 Million/yr

The question arises, what is the value of this additional experimentation? Our economics staff has advised us that such experimentation leads to new products, which lead to increased sales, and hence to added profits and to an increase in the equity of the researchers' firms. The formula we have used, which results from this analysis, is as follows:

- Sum the research over a 5 year period.
- Multiply by a factor of 15. This is the increase in equity (or value) experienced, on average (i.e., assuming typical success rates in the research), at the end of a further 5 years.

We have, therefore, obtained the value of the research on the Space Station by taking \$40 million/yr (the additional research due to Station), multiplying by 5 years (1991-1995), i.e., \$200 million, and multiplying that by 15, i.e., \$3,000 million. Discounted to 1986 present day value, this shows a benefit of \$686 million to the users.

We have assumed a factor of 6 (i.e., high technology, new), to derive a benefit to the nation of \$4,118 million.

The benefits to the user and the nation accruing from the materials processing products due to the Space Station occur in two areas--pharmaceuticals and crystals. The pharmaceuticals we investigated were interferon and three new, unspecified pharmaceuticals that are likely to be developed during the mission model period. We classified these new pharmaceuticals as Types A, B, and C. The crystals we investigated were Gallium-Arsenide and six new, unspecified semiconductors we classified as Types II-VI and D.

Pharmaceutical production in space would occur during the final stage of the production process when the material is purified. The mass of the pharmaceuticals delivered to the Space Station to be purified would be approximately 40 percent of the mass initially produced on earth. Table 2-5 gives the masses produced each year at the Station relative to the no Station scenario.

Table 2-6. Shows the value per pound of the products, taken from our Space Processing section of this report. When this value is multiplied by the mass produced per year, and discounted, we obtain the value of the products to the users, as shown in Table 2-7. Since these are singularly new products, we multiply by a factor of 6 to obtain the value to the nation.

The Space Processing benefits are summarized in Table 2-8. Very large benefits arise in this area, as a result of the high value of the new products. In our scenario, interferon produces \$14 billion of benefits alone, or 40 percent of the total benefits to the nation, of \$36 billion. It should

Table 2-5. Delta Mass Produced, Pound (Scenario 6-6A)

Item	Year											Total
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Pharmaceutical												
• Interferon	26	38	44	49	51	49	44	40	31	22	13	407
• Type A	0	0	0	0	26	38	44	49	51	49	44	301
• Type B	0	0	0	0	0	0	0	26	38	44	49	157
• Type C	0	0	0	0	0	0	0	0	26	38	44	108
Total	26	38	44	49	77	87	88	115	146	153	150	973
Crystal												
• GaAs	75	172	313	507	782	-821	-669	-359	0	0	0	0
• Type II-VI	0	0	0	0	0	119	262	502	899	1,521	2,488	5,791
• Type D	0	0	0	0	0	0	0	0	50	150	200	400
Total	75	172	313	507	782	-702	-407	143	949	1,671	2,688	6,191
Grand total	101	210	357	556	859	-615	-319	258	1,095	1,824	2,838	7,164

Table 2-6. Value of Space Processing Products, $\overline{\$M}$/lb

	Year										
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Pharmaceuticals	24.95	21.55	19.275	18.15	17.025	15.875	15.875	15.875	15.875	15.875	15.875
GaAs	0.36	0.29	0.23	0.18	0.16	0.14	0.13	0.12	0.12	0.11	0.11
Type II-VI/D	0.73	0.58	0.45	0.37	0.32	0.28	0.26	0.24	0.23	0.23	0.23

Table 2-7. Discounted Value of Space Products to the Users, $\overline{\$M}$

Item	Year											Total
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Pharmaceutical	424	474	443	417	562	540	476	572	651	619	540	5,718
Crystal												
• GaAs	18	30	38	44	54	-45	-30	-14	0	0	0	95
• Type II-VI/D	0	0	0	0	0	13	24	37	62	98	141	375
Totals	442	504	481	461	616	508	470	595	713	717	681	6,188

be noted that if we had carried out the analysis to a few years beyond 2000, the other (unspecified) new pharmaceuticals would have exceeded interferon in value.

Table 2-8. Summary of Discounted Benefits for Space Processing, $M

Item	To Users	To Nation
Reduced mass to orbit	65	195
Additional experimentation	686	4,118
Pharmaceuticals		
• Interferon:	3,165	14,243
• Type A	651	3,906
• Type B	429	2,574
• Type C		
Crystals		
• GaAs	95	427
• Type II-VI	343	2,058
• Type D	23	138
Total	6,930	36,497

COMMERCIAL COMMUNICATIONS

In the commercial communications area, seven categories were identified to have benefits that could be quantified. These categories are:

- Deployment of spacecraft appendages (i.e., antennas, solar arrays) at the Space Station
- Checkout of the spacecraft and its payload at the Space Station before transferring to its final orbit.
- Assembly of the spacecraft and its payload(s) at the Space Station
- Low thrust transportation (0.1 g) from the Space Station to geosynchronous orbit on the OTV and using the spacecraft's apogee propulsion system (assumed to be a low thrust storable system).
- Transportation from Earth to Space Station and from there to geosynchronous orbit at lower cost due to a higher load factor achieved on the Shuttle and the use of the reusable cryogenic space-based OTV.

- Geoservicing of satellites at geosynchronous orbit using specialized geoservicing satellites and equipment which allow updating of the spacecraft payloads periodically to keep up with new technology and varying market demand. Also to resupply propellants and, if necessary, fix or repalce failed components.

- New missions which become possible due to the entry of more commercial firms as the result of lower total costs with the Space Station.

For the seven categories, the values of the benefits were determined to be a fraction of a cost item. As seen in Table 2-9, the deployment, assembly, and low thrust benefit values were based on the spacecraft cost, while geoservicing and new mission benefits values were developed from the program costs. The remaining categories derived their values from insurance cost savings or the decrease in transportation costs. The cost items were based, in turn, on typical costs per pound of spacecraft (in circularized geosynchronous orbit), as also shown in Table 2-9. The results shown in the table are benefits per pound of spacecraft.

Table 2-9. Value of Benefits per Pound of Spacecraft

Deployment	0.05 x spacecraft cost = 0.05 x 25,000 \$/lb = 1,250 \$/lb
Checkout	0.10 x insurance cost = 0.10 x 3,500 \$/lb = 350 \$/lb
Assembly	spacecraft cost/lb x Δlb = 25,000 \$/Δlb = 25,000 \$/Δlb
Low Thrust	0.06 x spacecraft cost = 0.06 x 25,000 \$/lb = 1,500 \$/lb
Transportation	Δtransportation cost = 1.0 x 6,000 \$/lb = 6,000 \$/lb
Geoservicing	0.15 x program cost = 0.15 x 50,000 \$/lb = 7,500 \$/lb
New Missions	4.0 x program cost = 4.0 x 50,000 \$/lb = 200,000 \$/lb

Table 2-10 shows the mass of communication spacecraft involved in each of these benefit areas in Mission Scenario 6. The mass shown in the assembly benefit area is the difference in masses between Mission Scenario 6 and Mission Scenario 6A. Since, according to our study conclusions, the OTV only becomes operational in 1994, and communication satellites only use the Space Station in conjunction with the OTV, there is no communication satellite traffic through the Space Station before 1994.

Table 2-11 shows the dollar value of the benefits, i.e., the products of the numbers in the two previous tables. These dollar benefits have been discounted at 10 percent per annum starting from 1986, thus showing the present day value of the benefits in 1986.

Table 2-10. Mass of Communications Satellites Involved in Each Benefit (Klb)

Item	Year							Total
	1994	1995	1996	1997	1998	1999	2000	
Deployment	32.22	40.55	60.65	51.46	41.97	31.47	29.47	287.79
Checkout	10.3	19.3	20.1	21.0	21.0	12.0	12.0	115.7
Assembly	0	-1.5	1.5	3.9	3.5	3.5	3.6	11.5
Low thrust	43.12	54.75	76.20	62.93	44.14	43.47	54.24	378.85
Transportation	43.12	54.75	76.20	62.93	44.14	43.47	54.24	378.85
Geoservicing	15.0	24.0	33.32	28.82	25.67	21.67	21.67	170.15
New missions	2.4	2.4	9.68	1.9	3.6	7.8	3.9	31.68

Table 2-11. Discounted Value of Benefits to Communications Satellite Users (1984 $M)

Item	Year							Total
	1994	1995	1996	1997	1998	1999	2000	
Deployment	17	20	26	20	15	10	8	116
Checkout	2	3	2	2	2	1	1	13
Assembly	0	-14	-13	30	25	22	20	70
Low thrust	28	32	40	30	19	17	19	185
Transportation	111	127	159	119	75	66	74	731
Geoservicing	48	70	87	68	54	41	37	405
New missions	206	186	676	120	204	296	178	1,966
Totals	412	434	977	389	394	553	337	3,486

These results show that the new missions (which result from lower transportation and other costs in Mission Scenario 6) represent more than half the total benefits to the communications satellite users. Although represented by only nine additional satellites launched between 1994 and 2000, these provide valuable additional assets of nearly $2 billion to this industry. The other two large benefit areas are the lower transportation costs which provide $0.73 billion reduction in costs, and the introduction of geoservicing in 1996

which provides benefits in only four years of $400 million. This large benefit from geoservicing arises from the ability of the geoserviceable satellite owners to reconfigure their satellites every three or four years so as to update the payloads to the latest technology, to allow for changes in a rapidly changing market, and to prolong the useful life of the satellites.

The benefits to the nation are derived from the benefits to the users by multiplying by the following factors.

$$\left.\begin{array}{l}\text{Deployment}\\ \text{Checkout}\\ \text{Assembly}\\ \text{Low thrust}\\ \text{Transportation}\end{array}\right\} \times \ 3.0$$

$$\begin{array}{lll}\text{Geoservicing} & \times & 4.5\\ \text{New missions} & \times & 6.0\end{array}$$

The factor of three for the first five benefit areas reflects the fact that these are purely cost savings benefits and do not provide any new technology or new capability to the nation. The new missions, represented by nine additional satellites launch (about 700 additional transponders), should provide significant advance in services offered and, therefore, have a high multiplicative factor. The geoservicing represents an intermediate situation where both new services and cost reduction result.

Table 2-12 summarizes the estimated (discounted) value of the benefits to the commercial communications user community and to the nation.

Table 2-12. Summary of Discounted Commercial Communications Benefits (1984 $M)

Benefit Area	To The Users	To The Nation
Deployment	116	348
Checkout	13	39
Assembly	70	210
Low thrust	185	555
Transportation	731	2,193
Geoservicing	405	1,822
New missions	1,966	11,796
Total	3,485	16,963

It is seen that the greatest benefit to the nation, valued at about $12 billion, accrues from the services resulting from the nine new satellites. The other benefits are valued at an additional $5 billion for a total due to communications satellites of $17 billion.

It is worth noting that significant additional benefits, both to users and to the nation, would result if the development of the OTV would be brought forward so that the OTV can become operational at the same time as the Space Station. Although we have not performed a detailed analysis of the resulting trade-off, an approximate analysis based on a simple ratio of the years of operation involved, including the effect of discounting, gives the following results:

Item	Value of Benefits ($B)	
	Users	Nation
Space Station IOC 1991 OTV IOC 1994	3.5	17.0
Space Station and OTV IOC 1991	6.0	29.1
Difference	2.5	12.1

The effect shown above, of an additional present day value to the nation of $12.1 billion by bringing the OTV IOC to 1991, would be shown to be even greater by a more detailed analysis, since there is a large surge of communications satellite launches in the years 1991 - 1993 (which could take advantage of the OTV) with a relative slowing down in the mid-1990's.

NATIONAL SECURITY

In the area of national security, we have established six separate benefit categories:

- Lower transportation costs
- Low (0.1 g) thrust
- Checkout in low earth orbit
- Assembly in low earth orbit
- Space test program (STP)--A sortie mission can be carried out at the Space Station in Mission Scenario 6 and achieve vastly more exposure hours in the space environment than the corresponding missions could achieve using only the Shuttle in Mission Scenario 6A.

- Geoservicing of DOD satellites in the geosynchronous orbit can prolong the satellites' life; increase their ability to survive various threats by, for example, having more capability for orbital maneuvering; and allow for additional exercise of these satellites' ability to maneuver from location to location in space in military exercises or as operational conditions allow.

The benefits from the first four categories are similar to the corresponding categories in the commercial communications area, and the reader is referred to that section for a description. The masses involved are shown in Table 2-13. These represent the difference, in each year, between Mission Scenario 6 and 6A; hence the occasional negative numbers.

Table 2-13. Mass of DOD Satellites Involved in Each Benefit (Klb)

Item	Year							Total
	1994	1995	1996	1997	1998	1999	2000	
Checkout	159.5	142	169	182	131.5	143	159	1,086
Assembly	7	-5	0	2	0	-5	7	6
Low thrust	63	46.5	38.5	61	49.5	50	43	351.5
Transportation								
a. LEO	60.5	55.5	72.5	55.5	58	55.5	60.5	418
b. GEO	63	46.5	38.5	61	49.5	50	43	351.5

The cost savings per pound used are:

- Checkout 350 $/lb
- Assembly 25,000 $/lb
- Low thrust 1,500 $/lb
- Transportation - LEO 700 $/lb
- Transportation - GEO 6,000 $/lb

Table 2-14 shows the resulting non-discounted and discounted cost savings to the users.

The last two categories of benefits, STP and geoservicing, result from a qualitative improvement in development and operational capabilities. The value of benefits accruing from these two features of the Space Station are difficult to assess with high confidence. A proper analysis would require very specific analysis of each affected DOD program, the definition of comparable mission profiles in both Mission Scenarios 6 and 6A, and threat scenarios.

Table 2-14. Cost Savings

Item	Year							Total
	1994	1995	1996	1997	1998	1999	2000	
VALUE TO THE USER, $M/YR (NON-DISCOUNTED)								
Checkout	78	70	83	90	64	70	78	533
Assembly	175	-125	0	50	0	-125	175	150
Low thrust	95	70	58	92	74	75	65	529
Transportation								
LEO	42	39	51	39	41	39	42	293
GEO	378	279	231	366	297	300	258	2,109
Total	768	333	423	637	476	359	618	3,614
VALUE TO THE USER, $M/YR (DISCOUNTED)								
Checkout	35	28	33	29	18	18	18	179
Assembly	75	-48	0	15	0	-33	40	49
Low thrust	41	27	22	2[illegible]	21	19	15	174
Transportation								
LEO	18	15	20	12	11	10	10	96
GEO	163	108	89	115	84	76	59	694
Total	332	130	164	200	134	103	142	1,192

What we have done in this study is to place the dollar value of these benefits in the right ball-park. We have chosen as the measure of this dollar value the following quantities which are available from our study.

For STP sortie missions:

- Mass of equipment launched to low earth orbit
- Exposure hours times the number of STP programs

For geoserviced satellites:

- The mass of geoserviceable satellites launched to geosynchronous orbit
- The mass of propellants and other material taken to these satellites in geoservicing missions

These numbers are as follows.

Table 2-15. Benefits of STP Sorties and Geoservicing (1984 $M)

	Year									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
STP Sorties										
Mission Scenario 6A										
Mass launched (lb)	7,000			7,000			7,000			7,000
Exposure hours	170			170			170			170
x number of programs			(10 days x 70% duty cycle)							
Mission Scenario 6										
Mass launched (lb)	5,000		5,000		5,000		5,000		5,000	
Exposure hours	1,500		1,500		1,500		1,500		1,500	
x number of programs			(90 days x 70% duty cycle)							
Geoservicing										
Mission Scenario 6 (only)										
Spacecraft mass launched (lb)						12,000	6,000	18,400	6,400	
Geoservicing mass launched (lb)						5,000	2,360	6,200	2,430	

To obtain the ball-park value of these new types of missions, we have used the following approximate calculations.

A typical STP sortie program costs $50 million and, in the Shuttle, achieves 170 hours of space exposure (i.e., hours of useful data). The value to the DOD is estimated, as explained earlier, at four time the cost (i.e., $200 million). For the corresponding Space Station case, we calculate the value as being proportional to the mass carried up into space and to the exposure time raised to the power of 0.75 (to allow for a law of diminishing returns). This means that each of the Space Station missions is valued at $731 million as compared to $200 million for the Shuttle missions.

A typical satellite cost, including the ground system costs, works out to about $50 thousand per pound of satellite. The corresponding value of the program, by the same arguments used earlier, is about four times more, or $200 thousand per pound. We now assume that the increase in value to the DOD of geoservicing is in proportion to the mass carried up in the geoservicing missions. This is a reasonable first order assumption since it provides more mass in orbit. Since this mass is mainly propellant, however, and since it is carried up on an "as opportunity allows," the cost of doing this is negligible compared to its value. We therefore assess the benefit at the rate of $200 thousand per pound of geoservicing material carried up.

Table 2-16 shows the resulting net benefits to the user (DOD) resulting from Mission Scenario 6 relative to 6A, discounted 10 percent per year to 1986 present day values.

Table 2-16. Discounted Value of the Value-Added Benefits to National Security Users (DOD), $M (1984)

Item	Year										Total
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
STP Sorties	314		350	-86	283		167		186	-46	1,168
Geoservicing						349	148	350	124		971
Total	314		350	-86	283	349	315	350	310	-46	2,139

Both of these benefits areas fall in the category of new missions (never been done before) and we assign a high multiplicative factor of 5.5 to obtain the benefits to the nation.

The National Security benefits are summarized in Table 2-17. The largest benefits accrue from the new capabilities represented by the availability of geoservicing and the added exposure time available for STP missions. These two together account for 65 percent of the benefits to the DOD, and 75 percent of the benefits to the nation.

Table 2-17. Summary of Discounted National Security Benefits (1984 ($M)

Item	To Users	To Nation
Lower transportation costs		
LEO	96	288
GEO	694	2,082
Low thrust	174	522
Checkout in LEO	179	537
Assembly in LEO	49	147
Geoservicing	971	5,340
STP sorties	1,168	6,424
Totals	3,331	15,340

SPACE TECHNOLOGY

The benefits obtained from the Space Station in the area of space technology are simple to understand but difficult to put a definite value on. The benefits are simply that they provide us the options to do missions, to start industries, and to perform scientific investigations in the future which we could not as a nation or as individual users of space do without this pioneering space technology work.

Specifically, as explained in the section on space technology, we have targeted six potential space initiatives which this country may be interested in pursuing in the future, and have designed the space technology mission model for the Space Station towards having the technology problems solved and demonstrated. These six initiatives and the years that we are aiming to have the technology ready and be able to do these missions with the station and without the station are:

	With Station	Without Station
• Geosynchronous multifunction communications platform	2001	2003
• Large astronomical observatory spacecraft	2002	2004
• Global environment monitoring systems	2003	2005
• Earth-orbiting microgravity facility	2004	2006
• Lunar operations base	2006	2013
• Manned Mars mission	2008	2018

Without the Space Station (i.e., for Mission Scenario 6A) we would not have the technology readiness for these initiatives in the time period through 2000. Instead, the nation's space technology effort would be concentrated in the 1990's in investigating a manned Space Station for the beginning of the next century. The option to perform the above high initiative mission would thus be postponed to the later dates indicated above.

The benefits fall into two categories:

- Lower cost of technology readiness.
- Value of earlier mission readiness.

The lower costs result because we can perform many of the space technology missions required more efficiently with the Space Station than without. The cost savings are represented by the differences between Mission Scenarios 6 and 6A, as described in the Technology Development section of the Mission Analysis volume. The cost differentials have been estimated there, and are summarized in Table 2-18. These savings occur in the time period 1991-2000 and should be discounted to 1986 present value. The table shows, in the two right hand columns, the discounted costs, both to the Station users (i.e., NASA) and to the nation. The latter are assumed to be three times the savings to the users.

Table 2-18. Lower Costs of Technology Readiness

Initiatives	Costs ($ millions)		Delta Costs ($ millions)	Discounted Cost Savings ($ millions)	
	No Station	Station		To Users	To Nation
Geosynchronous multifunction communications platform	894	660	234	90	270
Large astronomical observatory	694	500	194	75	225
Global environment monitoring system	236	99	137	53	159
Earth orbiting microgravity facility	600	500	100	38	114
Lunar operations base	680	600	80	31	93
Manned mars mission	2,674	2,400	274	105	315
Total	5,778	4,759	1,019	392	1,176

The value of earlier mission readiness was quantified by the following process:

- Estimate the value to the nation of performing the high initiative missions.
- Calculate the present day value, discounted from the technology readiness date with a Space Station (Mission Scenario 6).

- Calculate the present day value, discounted from the technology readiness date without Space Station (Mission Scenario 6A).

- The difference between the two discounted values is taken to be the dollar value of the benefit due to the Space Station--i.e. the value of earlier technology readiness for the high initiative missions.

We do not believe that it is meaningful, in this case, to discuss the benefits to the user, since the user (in one sense) is the nation. In another sense, the user is NASA; and it would be a closed loop argument to justify the Space Station on the basis that it benefits NASA.

We thus have to estimate the value to the U.S. population of achieving each of these high initiative missions. We have interpreted this value as follows:

What is the cumulative sum of the value that each American household would place, in 1986 (our present value year), of the U.S. doing each of the high initiative missions? By "value" we mean the maximum amount of tax money, spread over a number of years, that the individual household would be willing to spend to achieve the mission.

This value could be estimated quite well by taking a scientific poll, although the results would obviously vary with the economic and sociopolitical climate at the time the poll was taken. We have, so to speak, mentally conducted a poll which reflects our judgment of how the U.S. may feel about these subjects in 1986. We have extrapolated a fairly positive socio-economic climate in this time period (otherwise the whole question of the Space Station is moot), not nearly a "boom" but definitely out of a recession and with economic growth and expectations of a continued growth. Our estimates, based on many polls conducted on behalf of Rockwell over many years relating to the public's interest of and support for space activities, assume a distribution of how much money it is worth to the population to do each initiative.

We present our results in Table 2-19, in which we divided the population into five typical segments, from the very enthusiastic to the apathetic and the opponents, and assigned a per household value to each of these segments--i.e., the maximum expenditure, in terms of dollars per year over ten years, each household would be willing to spend.

These values are discounted by multiplying by a "discount factor." This is the difference between the discounting factor $(0.9)^n$ taken from 1986 to each of the two technology readiness years (with and without a Space Station). The resulting values, shown in the last column in the table, represent the value added, according to our methodology, by the Space Station.

The results indicate that \$14.7 billion of benefits to the nation result from the Space Station in the area of space technology. The main benefits

Table 2-19.. Value of Future Initiatives to U.S. Households

Future Initiatives	10% Enthu-siasts	25%	30%	25%	10% Oppo-nents	Total Value ($M)	Discount Fraction	Discounted Benefits to Nation ($M)
Geosynchronous multifunction communications platform	48	40	24	12	0	30,000	0.0391	1,174
Large astronomical observatory spacecraft	120	100	36	6	0	59,160	0.0352	2,083
Global environment monitoring systems	96	75	36	8	0	41,150	0.0317	1,303
Earth-orbiting microgravity facility	18	10	2	0.50	0	5,025	0.0285	143
Lunar operations base	180	120	36	6	0	60,300	0.0634	3,823
Manned Mars mission	240	150	48	6	0	77,400	0.0641	4,965
				Total				13,491
Based on 120 million households in the U.S. in 1986.								

are that the Space Station gives the nation the option to reach some potentially important goals in the next century. Our analysis shows that the most useful contributions are:

- Allowing a manned Mars mission in 2008 rather than in 2018
- Allowing a manned lunar operations base in 2006 instead of 2013
- Allowing a large astronomical observatory in 2004 instead of 2002

Other substantial benefits also arise in the communications platform and global environmental areas and simply from cost savings worth over $1 billion.

SUMMARY OF QUANTIFIABLE BENEFITS

Tables 2-20 through 2-24 summarize the quantifiable benefits discussed above, as well as the methods used to derive them.

Table 2-25 summarizes the quantifiable benefits to the Space Station users and to the nation as a whole. These are shown in billions of 1984 dollars, discounted at 10 percent per year, and brought to present day value in 1986. Out of the total benefits of $17.3 billion to the users, $6.9 billion, or 40 percent, are due to space processing, with approximately 20 percent being due, respectively, to science and applications, commercial communications, and national security.

The total benefits to the nation are $94.9 billion, or about 5.5 times the benefits to the users. This high factor generally reflects the high technology, "never-been-done-before," nature of the Space Station's new missions. The largest benefit area is, as for the users, space processing, with $36.5 billion, or nearly 40 percent of the total, with roughly equal contributions in the remaining four areas.

In each area, the benefits fall clearly into two categories:

- Cost savings
- Value added

We summarize in Table 2-26 the breakdown in these categories for each mission area. In all cases, except science and applications, the "value added" benefits exceed the "cost reduction" benefits. Over all, the ratio is 3 to 1 for the users and 6 to 1 for the nation. This is a good indication that the effects of the Space Station will be felt primarily in advancements in the fields which the nation values--science, new technologies, new products and services, and national security--rather than the more pedestrian economic benefits of being able to do more efficiently what we are already doing.

The ultimate usefulness of a benefits analysis is for the nation to decide whether the benefits to be derived by the nation are worth the investment that has to be made to obtain these benefits. It is not sufficient for the benefits to exceed the investment; they should exceed the investment by a large enough margin so that the project can compete successfully with alternative uses of scarce resources. The proper comparison is between the following two items:

- The dollar value of the quantifiable benefits to the nation derived from the Space Station, discounted to present day value
- The investment that must be made by the government, similarly discounted, to cause these benefits to happen; i.e., the DDT&E and production costs for the initial and growth Space Station, and OTV.

Table 2-20. Science and Applications Benefits Through 2000

							DISCOUNTED BENEFITS, $\$\overline{M}$ TO USERS	DISCOUNTED BENEFITS, $\$\overline{M}$ TO NATION
• LOWER TRANSPORTATION COSTS								
• 32.8 vs 69.4 SHUTTLE FLIGHTS x $\$77\overline{M}$/FLT							1122	3,366
• LESS MISSION HARDWARE								
• PLATFORM DDT&E (\$1.6B IN 1992 vs \$0.26B IN 1995)							480	1440
• VALUE OF ΔMISSIONS								
ΔMISSIONS VALUE DISTRIBUTION, \$/HOUSEHOLD/YR	10%	25%	30%	25%	10%	AVERAGE		
• ASTROPHYSICS	18	6.0	1.2	0.3	0	3.735	431	1,724
• ENVIRONMENTAL	6	2	0.5	0.1	0	1.28	148	590
• PLANETARY	24	14.4	1.4	0.6	0	6.570	758	3,032
• RESOURCE OBSERV.	4	2	0.5	0.1	0	1.08	124	498
• LIFE SCIENCE	5	2	0	0	0	1.00	115	462
• SPACE PROCESSING	2	0.5	0.1	0.05	0	0.37	43	171
• COMM RESEARCH	1	0.5	0	0	0	0.22	26	102
120 $\overline{M}$ HOUSEHOLDS × 10 YEARS ×						14.255		
							3247	11,385

Table 2-21. Space Processing Benefit Through 2000

		DISCOUNTED BENEFITS, $\$\overline{M}$ TO USERS	DISCOUNTED BENEFITS, $\$\overline{M}$ TO NATION
• REDUCED MASS TO ORBIT			
• Δ(MASS x COST/LB) = 796 → 661 KLB, 2000 → 1300 \$/LB		65	195
• VALUE OF ADDITIONAL EXPERIMENTATION			
• Δ RESEARCH \$ x 15 = 40 $\$\overline{M}$ x 5 x 15		686	4,118
• PHARMACEUTICALS			
• INTERFERON:	407 LB x 17.8 $\$\overline{M}$/LB	3,165	14,243
• TYPE A	301 LB x 15,875 $\$\overline{M}$/LB	1,473	8,838
• TYPE B	157 LB x 15.875 $\$\overline{M}$/LB	651	3,906
• TYPE C	108 LB x 15.875 $\$\overline{M}$/LB	429	2,574
• CRYSTALS			
• GaAs	1849 LB x 5 YRS EARLIER x 244 $\$\overline{K}$/LB	95	427
• TYPE II-VI	5791 LB x 142 $\$\overline{K}$/LB	343	2,058
• TYPE D	400 LB x 230 $\$\overline{K}$/LB	23	138
		6,930	36,497

Table 2-22. Commercial Communications Benefits Through 2000

	DISCOUNTED BENEFITS, $M	
	TO USERS	TO NATION
• LOWER TRANSPORTATION COSTS		
• 1 × ΔCOSTS = 1 × 6000 $/LB × 379,000 LB	731	2193
• LOW (0.1g) THRUST		
• .06 × SPACECRAFT COSTS = .06 × 25,000 $/LB × 379,000 LB	185	555
• DEPLOYMENT IN LEO		
• .05 × SPACECRAFT COSTS = .05 × 25,000 $/LB × 288,000 LB	116	348
• CHECKOUT IN LEO		
• .10 × INSURANCE COSTS = .10 × 3500 × 116,000 LB	13	39
• MULTI-USER SYSTEMS		
• 1 × ΔS/C COSTS = 1 × 25,000 $/LB × 11,500 LB	70	210
• GEOSERVICING		
• .15 × PROGRAM COSTS = .15 × 50,000 $/LB × 170,000 LB	405	1822
• 9 MORE SATELLITES		
• 4 × PROGRAM COSTS = 4 × 50,000 $/LB × 31,700 LB	1966	11,796
	3485	16,963

Table 2-23. National Security Benefits Through 2000

	DISCOUNTED BENEFITS, $M	
	TO USERS	TO NATION
• LOWER TRANSPORTATION COSTS		
• LEO: ΔCOSTS = $700/LB × 418. LB	96	288
• GEO: ΔCOSTS = $6000/LB × 351.500 LB	694	2082
• LOW (0.1g) THRUST		
• 06 × SPACECRAFT COSTS = 06 × 25.000 $/LB × 351.500 LB	174	522
• CHECKOUT IN LEO		
• 01 × SPACECRAFT COSTS = 01 × 25.000 $/LB × 1,086.000 LB	179	537
• ASSEMBLY IN LEO		
• SPACECRAFT COST/LB × MASS = 25.000 $/LB × 6000 LB	49	147
• GEOSERVICING		
• SPACECRAFT COST/LB × GEOSERVICING MASS = 50.000 $/LB × 15.990 LB	971	5340
• STP SORTIES		
• ∝ MASS × (HOURS)$^{0.75}$ • 294.000 $/LB × 4 — STATION: MASS 25.000 LB, HOURS 7500; NO STATION: MASS 28.000 LB, HOURS 680	1168	6424
	3331	15.340

Table 2-24. Space Technology Benefits Through 2000

• LOWER COSTS OF TECHNOLOGY READINESS

	COSTS, $M		DISCOUNTED BENEFITS, $M	
	NO STATION	STATION	TO USERS	TO NATION
• GEOSYNCHRONOUS MULTIFUNCTION COMM PLATFORM	894	660	90	270
• LARGE ASTRONOMICAL OBSERVATORY	694	500	75	225
• GLOBAL ENVIRONMENT MONITORING SYSTEM	236	99	53	159
• EARTH ORBITING MICROGRAVITY FACILITY	600	500	38	114
• LUNAR OPERATIONS BASE	680	600	31	93
• MANNED MARS MISSION	2674	2400	105	315
			392	1176

• VALUE OF EARLIER MISSION READINESS

	VALUE OF MISSION, $M	ΔYRS	FRACTION	TO USERS	TO NATION
• GEOSYNCHRONOUS MULTIFUNCTION COMM PLATFORM	30,000	2	0391		1174
• LARGE ASTRONOMICAL OBSERVATORY	59,160	2	0352		2083
• GLOBAL ENVIRONMENTAL MONITORING SYSTEM	41,150	2	0317		1303
• EARTH ORBITING MICROGRAVITY FACILITY	5,025	2	0285		143
• LUNAR OPERATIONS BASE	60,300	7	0634		3823
• MANNED MARS MISSION	77,400	10	0641		4965
				392	14,667

Table 2-25. Summary of Benefits (1984 $B)

	TO USERS	TO NATION
• SCIENCE & APPLICATIONS	3.2	11.4
• SPACE PROCESSING	6.9	36.5
• COMMERCIAL COMMUNICATIONS	3.5	17.0
• NATIONAL SECURITY	3.3	15.3
• SPACE TECHNOLOGY	0.4	14.7
TOTAL	17.3	94.9

• DISCOUNTED AT 10% PER YR
• 1986 PRESENT YEAR VALUE

Table 2-26. Breakdown of Benefits by Cost Reduction and Value Added in 1984 $B, Discounted 10% per Year to 1986 Present Day Value

Area	To Users		To Nation	
	Cost Reduction	Value Added	Cost Reduction	Value Added
Science and applications	1.6	1.6	5.2	6.2
Space processing	0.1	6.8	0.2	36.3
Commercial communications	1.1	2.4	3.4	13.6
National security	1.2	2.1	3.6	11.7
Space technology	0.4	0	1.2	13.5
Total	4.4	12.9	13.6	81.3

Operational costs of the Space Station and OTV are reimbursable to the government by the users, and are therefore not included in the investment.

This comparison is shown in Table 2-27. The benefits are broken down as cost savings and value added; and the investment into Space Station and OTV.

The comparison shows a favorable relationship, with discounted benefits to the nation of $94.9 billion, for a discounted investment of $7.6 billion. The cost savings to the nation of $13.6 billion by themselves exceed the investment by a factor of 1.8, although they are spread out between a variety of government and private sector users. The overall benefits to investment ratio, for the quantifiable benefits only, is 12.5. This is a very attractive ratio for any new venture, either in the government or in the private sector, and can be expected to compete favorably with other potential uses of the same funds.

The decision on the value of the Space Station must take into account two further considerations, both of which make the Space Station more attractive:

- We have only accounted for quantifiable benefits through the year 2000. Since the Space Station and OTV will probably be operational for another 10 years, to about 2010, additional benefits, potentially large, will accrue (although their present day value in 1986 is reduced by the discounting process).

- There are additional non-quantifiable benefits due to the presence of the Space Station. These may, in fact, be the dominant benefits.

Table 2-27. Benefits Versus Investment

BENEFITS TO THE NATION		INVESTMENT BY U.S. GOVERNMENT	
• COST SAVINGS	$13.6B	• SPACE STATION	$6.8B
• VALUE ADDED	$81.3B	• OTV	$0.8B
	$94.9B		$7.6B

BENEFITS / INVESTMENT = 12.5

NON-QUANTIFIABLE BENEFITS

As discussed earlier, the Space Station provides a number of more general benefits than those related to the specific missions it performs or helps to perform. These benefits result more from the very existence of a Space Station rather than from what it does. Since these benefits are very diffuse, are perceived very differently by different people and under different circumstances, and are considered large or small depending on what socio-economic goals the nation is pursuing, we do not see any purpose in trying to place a dollar value on these. We call these the non-quantifiable benefits.

In order to understand what benefits we are looking for in this category, we quote below part of the press announcement of President Reagan's National Space Policy released on July 4, 1982.

> *"The President's Directive reaffirms the national commitment to the exploration and use of space in support of our national well-being, and establishes the basic goals of United States space policy which are to:*
>
> *-- strengthen the security of the United States;*
> *-- maintain United States space leadership;*
> *-- obtain economic and scientific benefits through the exploitation of space;*
> *-- promote international cooperative activities in the national interest; and*
> *-- cooperate with other nations in maintaining the freedom of space for activities which enhance the security and welfare of mankind."*

And, an extract from his speech on the same day:

> *"To insure that the American people keep reaping the benefits of space and to provide general direction for our future efforts, I recently approved a National Space Policy Statement which is being released today.*
>
> *Our goals for space are ambitious, yet achievable. They include:*
>
> *-- continued space activity for economic and scientific benefits;*
> *-- expanding private sector investment and involvement in space-related activities;*
> *-- promoting international uses of space;*
> *-- cooperating with other nations to maintain the freedom of space for all activities that enhance the security and welfare of mankind.*

-- *strengthening our own security by exploring new methods of using space as a means of maintaining the peace.*

"There are those who thought the closing of the western frontier marked an end to America's greatest period of vitality.

"Yet, we are crossing new frontiers everyday; the high technology now being developed, much of it a by-product of the space effort, offers us and future generations of Americans opportunities never dreamed of a few years ago. Today we celebrate American Independence confident that the limits of our freedom and prosperity have again been expanded by meeting the challenge of the frontier."

How the space station meets the President's objectives is summarized in Table 2-28.

Table 2-28. How Space Station Meets Presidential Objectives

Policy Objective	How Station Meets Objective	Contributing Mission Area*
Strengthen security	• Reduced transportation costs to orbit allows increased spending in other defense areas. • Mission survivability and responsiveness improved by CANSAT and servicing capability from station. • Station enables flexible and complex R&D due to man's presence and long-duration experimentation capability. • Sophistication and size of satellites grow over time, on-orbit assembly permits large structure construction. • R&D leads to new defense mission capabilities. • Shuttle is freed up to be used strictly for transportation.	X DOD SP CC SA ST
Enhance economy	• Export of space station technology reduces balance of trade deficits. • New space station products lead to new industries and jobs.	X DOD X SP X CC X SA X ST

Table 2-28. How Space Station Meets Presidential Objectives (Cont)

Policy Objective	How Station Meets Objective	Contributing Mission Area*
	• Space station enables space missions to be performed cheaper and faster. • Promotes innovation which eventually permeates all industries.	
Promote global peace	• Pharmaceuticals processed through station involvement may cure diseases worldwide. • International cooperation leads to world peace. • Space technology reduces world hunger and ignorance. • Defense satellites deter offensive moves which threaten world peace. • Space research helps create unified vision of the world. Leads to recognition of a unified destiny.	X DOD X SP X CC X SA X ST
Promote international cooperation	• Opportunity for joint research projects (cf., Spacelab). • Provides foundation for future cooperative efforts on a larger scale (e.g., joint ownership of a station). • Technology transfer from U.S. space program to foreign space program. • Transfer of space hardware to foreign nations enables them to perform their missions faster. • Desire for cooperative efforts leads to regulations which favor such efforts thereby promoting future joint efforts.	DOD X SP X CC X SA X ST
Promote space commercialization	• Station provides capability for commercial operations in space. • Station reduces cost of doing business in space.	DOD X SP X CC

Table 2-28. How Space Station Meets Presidential Objectives (Cont)

Policy Objective	How Station Meets Objective	Contributing Mission Area*
Enhance science	• Long-duration research on effects of space environment on man forms stepping stone to manned planetary missions, space colonization.	SA X ST
	• Large structure assembly capability provides potential for advanced astronomy missions.	X SA X SP
	• Servicing from station extends life instrumentation thereby providing capability to obtain more data and expand technology faster and cheaper.	CC X SA X ST
	• Experimentation at station enables us to understand certain scientific processes so that research can be performed better on the ground.	X DOD X SP
Maintain U.S. leadership	• Station promotes innovation which leads to high technology economy.	X CC
	• Provides capability to perform the future missions required to maintain leadership in space exploration and development.	X SA X ST

*DOD = Department of Defense
SP = Space processing
CC = Commercial communications
SA = Science and applications
ST = Space technology

These objectives set the context for our discussion in this section. We have identified the following non-quantifiable benefits due to the Space Station:

- Science, engineering, and technology--An ambitious Space Station program encourages a positive and ambitious viewpoint of science, engineering, and technology by our youth. This attitude will be necessary in the future to maintain a technology lead over our competitors.

- Space Station is the "gateway to the Future"--The Space Station opens up many frontiers in the next century. The above quote is from the

NASA administrator, Mr. J. Beggs. We refer to a few things it can lead to, or contribute to:

- New space industries
- Energy from space
- The information society
- Exploring Earth and its environment
- Exploring the solar system
- Exploiting lunar and asteroid resources
- Understanding the universe

- Commercialization of space--Because the Space Station itself is modular, and because there is a variety of associated systems and services, from very small (e.g., docking ports) to very large (e.g., management of the bookings for Station), it is an excellent means for encouraging commercialization. This is discussed in a separate report we are producing. The Space Station has the potential for being the last major operational space system the government has to finance.

- Maintains the Nation's Manned Space Capability. Sometime early in the next century, the U.S. will have to replace the Shuttle, which will be reaching its end of life by then and be obsolete. Development of this Shuttle replacement will have to start in the early to mid-1990's. If this country is to have the technological base to manage and to develop such a high technology system it will be necessary to keep the NASA/industry team together through the intervening decade (1984-1994). This requires a challenging, ambitious, manned program or programs; otherwise both the NASA and the industry management, engineering, and production personnel will disperse to other activities. The Space Station fills this Shuttle replacement need perfectly.

- Space Leadership--If this country is to be perceived by its own citizens and by those of other countries as the leader in space, it must aim for very ambitious goals. The USSR, Europe, Japan, India, Brazil, and other nations are perceiving space as the foremost area of activity which distinguishes leader nations from follower nations. We can expect the competition in space to increase in the next 20 years, not decrease. The pinnacle of space leadership is undoubtedly manned space activity. Can we, for example, consider any nation a great technological leader which does not have a vigorous, active, and expanding manned space activity?

- Pride and Prestige--An ambitious Space Station program can contribute enormously to how Americans feel about themselves and their country (pride), and how people abroad perceive us (prestige). Figure 2-3 shows the enormous contributions made by space programs to our feelings of well-being, and to our ability to hold our heads high at home and abroad.

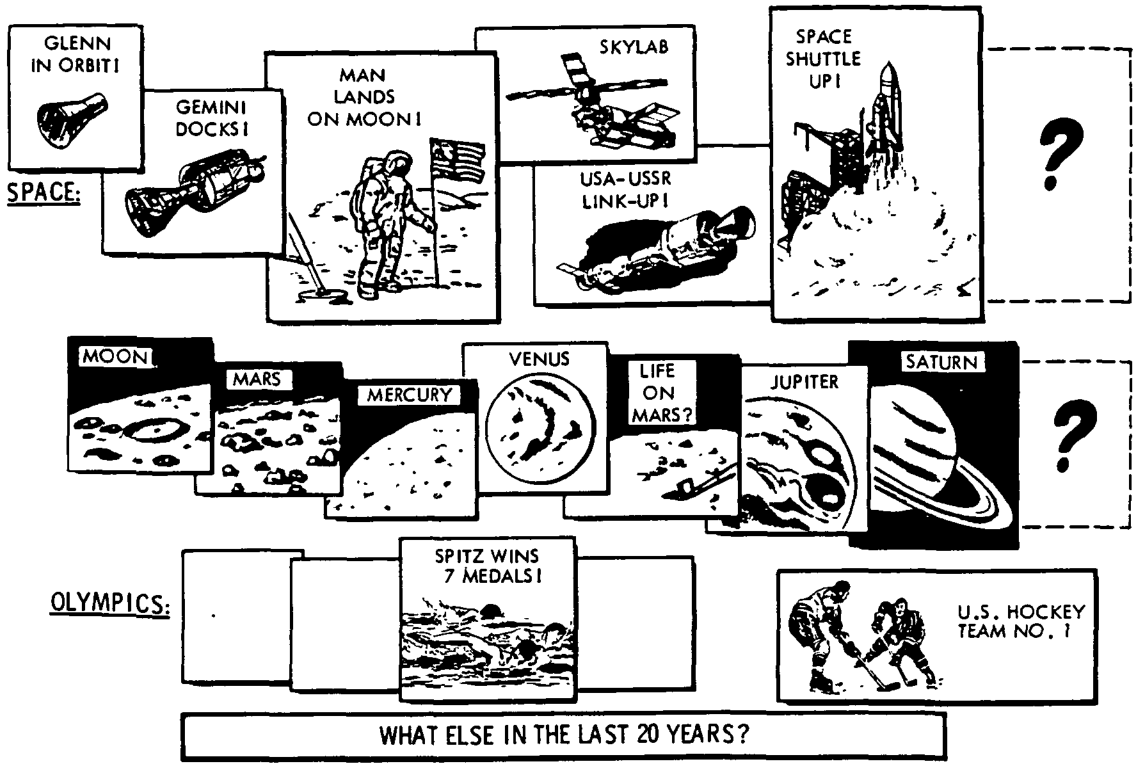


Figure 2-3. Pride and Prestige

THE BENEFITS FROM SPACE COMMERCIALIZATION

As a separate effort from the Space Station contract, Rockwell performed an analysis of commercial opportunities at the Space Station. The results of the analysis pertaining to national benefits summarized in this volume.

The benefits which the nation would derive from commercial utilization of the analysis pertaining to national benefits are summarized in this volume.

EMPLOYMENT

- Each of the new business opportunities identified in the study will require employees that possess a wide range of skills.
- Thousands of existing businesses will be involved in supplying the new businesses with hardware and services.
- The requirement for supporting hardware and services may result in the development of new businesses on earth.

Many of the new jobs created will involve high-technology skills. These skills will prepare Americans for designing and manufacturing future advanced products which will reduce or eliminate the need to import highly trained workers. The training required will necessitate new courses and schools to be developed which will result in new jobs for educators. Employment increases will produce a larger tax base, spur economic recovery, and reduce the demand for social services from the unemployed.

CAPITALIZATION

Collectively the identified new business opportunities will create the infrastructure from which new industries will develop. The facilities and experience will evolve into competing and complementary organizations. New products and innovations in processing will directly benefit the economy of the U.S. Newly developed technologies will also find application in established organizations.

PRODUCTS

Commercial Earth and Ocean Observations

This business opportunity will provide information to improve and/or expedite:

- Crop planning, maintenance, forecasting
- Range land and forest management

- Mineral and petroleum exploration
- Urban and regional land-use planning
- Water quality assurance

Commercial Materials Processing

Resulting benefits are:

- Production of raw materials which will significantly improve electronic devices including computers and sensors
- Production of raw materials for new drugs and medications to cure or treat major and "orphan" diseases
- Increased understanding of physical and biological processes

Commercial GEO Servicing; Multi-User Satellite Systems; Reusable OTV

Commercializing these services would result in both cheaper and expanded communications and resource observations.

Commercial Space Laboratory

This would result in the discovery and development of a broad range of new products and processes.

EXPORTS

New product and technology exports will reduce our balance of trade deficit.

NATIONAL PRESTIGE

A commercial space station would be tangible evidence of American ingenuity.